HOW A TREE GROWS

BY

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WITH 112 ILLUSTRATIONS

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PREFACE

THIS book is the expansion of some notes of lectures given to Forestry Undergraduates in Oxford.

While the name sufficiently explains the scope of the work, I have occasionally deviated into side issues, as, for instance, in the identification of timbers.

I doubt if the book would ever have reached the stage of publication had it not been for the assistance of Miss Helen Bancroft, D.Sc., who provided the illustrations. To her, also to Mr. W. E. Hiley, M.A., I am indebted for their kindness in reading the proofs. I have also to thank Miss Allchin for help in compiling the index.

The drawings were originally made to the scale indicated, but, in reproduction, they have been slightly reduced, so that the magnification shown is somewhat less than the reality.

W. S.

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The Cell

PLANTS consist wholly of cells, and to this statement trees are no exception. It is the aggregation of these cells that constitute wood, and as the production of this substance is the main object of forestry, it follows that a knowledge of the functions and properties of a wood-cell is fundamental to the study of tree growth.

In different trees, and in different parts of the same tree, one meets with cells of varying size, but even the largest wood-cells, such, for instance, as one may find in a broad ring of Scots Pine, are so small as to be no more than just visible with the aid of a fairly strong pocket lens. The bulk of the cells in a piece of wood are dead and incapable of undergoing further change, but they were not always in this permanent condition; and in various parts of a tree, cells that are young, active, and capable of change are to be found. In the stem itself such cells are met with chiefly at the apex and in the cambium—the zone of tissue, namely, that lies between the bark and the wood.

If a cell in its youngest stage be examined under a compound microscope (Figs. 1 and 2) it will be found to consist of three well-marked portions: (1) a wall, (2) protoplasm, (3) a nucleus.

The wall when quite young consists of cellulose, a substance having a definite chemical composition which is expressed by the formula $C_6H_{10}O_5$, that is to say, 100 parts by weight contain about 44·4 parts of Carbon, 6·2 parts of Hydrogen, and 49·4 parts of Oxygen. Not only has cellulose a definite chemical composition, but it is a substance that possesses fairly definite physical properties. It is, when pure, perfectly colourless, fairly elastic, and allows water and various solutions to pass through.

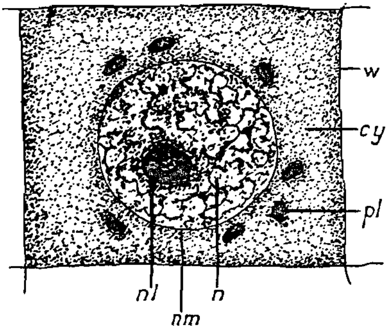

FIG. 1.—Embryonic Cell from Growing-point of a Phanerogamic stem, × *circa* 1250.

w = cell-wall; *cy* = cytoplasm; *pl* = plastid; *n* = nucleus; *nm* = nuclear membrane; *nl* = nucleolus.

The protoplasm, which occupies more or less completely the body of the young cell, is a sticky, viscid substance of complex and indefinite composition, containing the three elements found in cellulose, and, in addition, a comparatively large amount of nitrogen (about 16 per cent.), together with traces of sulphur and phosphorus. It is, in fact, the substance that a chemist, in the statement of an analysis of a food, returns as albuminoids or proteids. The body of protoplasm is differentiated into various kinds of plasm, such as leucoplasts, which build up the starch grains, chromoplasts, which construct the colouring matter, and chloroplasts, which form the green substance, not however present, as a rule, in a wood-cell, but

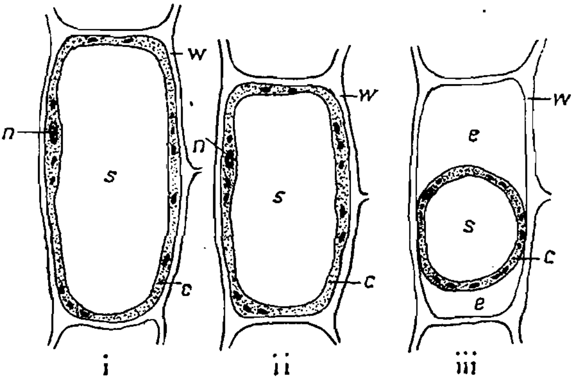

FIG. 2.—Young Parenchymatous Cell.

i, In the turgid state; ii, after treatment with 4% solution of nitre; iii, in 10% solution of nitre. *w*, wall; *c*, cytoplasm; *e*, nitre solution which has passed through cell-wall; *n*, nucleus; *s*, cell-sap.

abundant in certain other cells, notably those of the leaf. The general mass of undifferentiated protoplasm is called cytoplasm. Somewhere in the protoplasm of the cell—it may be in the centre, or close up against the wall, or at a point of crossing of protoplasmic threads—is to be found a differentiated portion of protoplasm called the nucleus, and somewhere in the nucleus is a further specialized part, the nucleolus. These two bodies take an active part in cell-division and multiplication.

Protoplasm is, for the most part, insoluble, and cannot be transported from one place to another in a plant, that is to say, it is not diffusible through a membrane. But by the agency of peptonising ferments it is readily converted into diffusible substances, of which perhaps the commonest is Asparagin, others being Glutamin, Leucin, and Tyrosin. If, in the analysis of a food-stuff, the chemist goes beyond Proteids, the substances just mentioned are usually grouped together under the term Amides. These may be regarded either as initial stages in the production of proteids, or as degradation products of that substance.

When quite young, many cells are roughly globular in shape, or, as it is called, isodiametric. Mature cells in wood and other parts of the stem of trees are much elongated, often tapering at both ends, and firmly dovetailing into each other.

Cell-Division

Cell-division—that is the multiplication of cells—can only take place in a cell in such a youthful stage that its cell-wall is still of cellulose, and whose internal cavity (lumen) contains protoplasm and a nucleus. It is by division that cells increase in number. One cell divides into two, these two may further divide into four, or one only may divide while the other remains permanently as a cell unit. This multiplication of cells in a stem takes place chiefly (*a*) at the ends of the leading shoot and of the branches, and (*b*) along the cambium mantle. It is at these places that the formation of new wood is taking place, the growth at the apices of shoots and branches resulting in an addition to the height of the tree and to the length of the branches, while growth in the cambium ring results in an addition to the thickness of the tree. The aggregation of these two forms of growth is represented by the increase in volume of the tree (Fig. 3).

But it is to be noted that multiplication of cells by division does not altogether account for growth in volume. Suppose, for a moment, that we compare a cell to an apple, or any similar body.

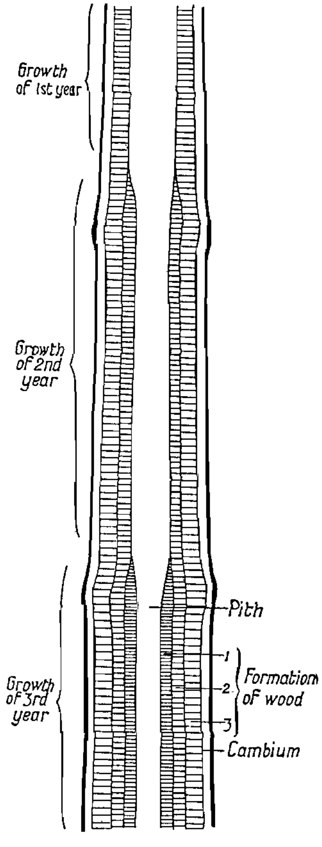

FIG. 3.—L.S., × ¼ (slightly diagrammatic from actual specimen) of a horse-chestnut twig showing part of 1st year's growth, 2nd year's and a part of 3rd year's. To show the position of the cambium and of the latest formation of wood.

We can divide an apple into two equal parts, and these two parts may be further divided into any reasonable number ; but the mere division of the apple does not result in any increase in volume. Similarly in the case of a cell. Through division we get increase in numbers, but not increase in volume.

Growth in Height

The matter can be best explained if we study growth-in-height a little more in detail. If we take, say, a young beech shoot, at the proper stage, namely, when it is rapidly elongating, usually about the end of May, we can, by the aid of the microscope, make the following observations (*Fig.* 4). If we take a *longitudinal section* from the extreme apex we shall find that there the cells are roughly isodiametric in shape, with thin walls of cellulose, and containing protoplasm that fills, or nearly fills, the internal space. It is at that point that cell-division is most active, and it is there that new cells are being rapidly created. This portion of the shoot is called the zone of cell-division. If, a little further back, say half an inch, we make another longitudinal section, we shall find that here the character of the cells is somewhat different. They are much longer than broad, their shape being such as would result from stretching the apical cells in one direction, namely, vertical. The protoplasm no longer fills, or nearly fills, the lumina of the cells. It is rather disposed as a skin (the protoplasmic sac, or primordial utricle), closely pressed against the inside of the cell-wall, with or without threads running across the cell from one side to the other (Fig. 2). This is the portion of the shoot where the cells are not increasing much in number but where they are markedly increasing in volume, and it has been called the zone of cell-elongation. In point of fact, there is no sharp line of demarcation between the zones of cell-division and of cell-elongation, but it is convenient to apply the former term to the apex of the growing shoot, and the latter term to the part of the shoot lying somewhat further back.

In the zone of cell-elongation the cells are not only longer than in the zone of cell-division, but they contain abundance of cell-sap, namely, water holding in solution sugar, organic acids (*e.g.* tannic, malic, oxalic), mineral matter and other substances. This cell-sap occupies spaces (vacuoles) in the protoplasm, and these vacuoles may be small and numerous, or they may be scarce and large. Sometimes, in fact, the whole internal cavity is one large vacuole, enveloped by the protoplasmic lining of the cell-wall (Fig. 2).

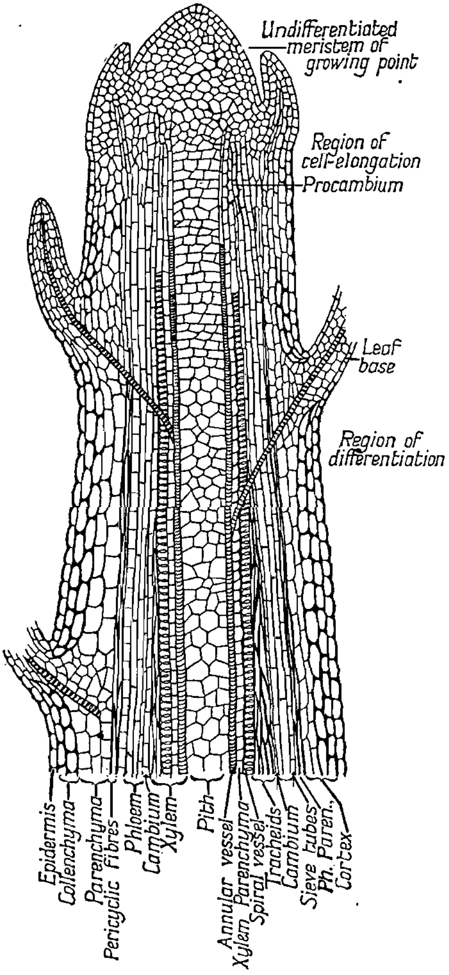

FIG. 4.—Diagrammatic longitudinal section through growing point of stem, showing region of cell-formation, cell-elongation and cell-differentiation.

Osmosis

Distension of the cells in the zone of cell-elongation is due to internal pressure set up by a force called osmosis. We can study the action of this force by constructing an artificial " cell " of a piece of hollow glass cylinder open at both ends. We first close one end by binding a membrane, say a piece of bladder, over it, then we fill the cylinder with a strong solution of sugar, and similarly close the other end. If this " cell " be placed in a vessel of water and left there for some time, we shall find that water has entered the closed chamber, and has caused internal pressure, which shows itself by the membrane at each end bulging out. It is a property of fluids that if a solution of a substance, like sugar, is separated from pure water by a membrane, the water will pass through the separating membrane and diffuse itself throughout the solution. Similarly, if a strong and a weak solution of the same substance be separated by a membrane, the weak solution will, to a greater or less extent, give up water to the stronger. Using the term that is applied to the vegetable-cell when subjected to internal osmotic pressure, we may call our artificial cell " turgid." Or the subject can be demonstrated as is shown in Fig. 5.

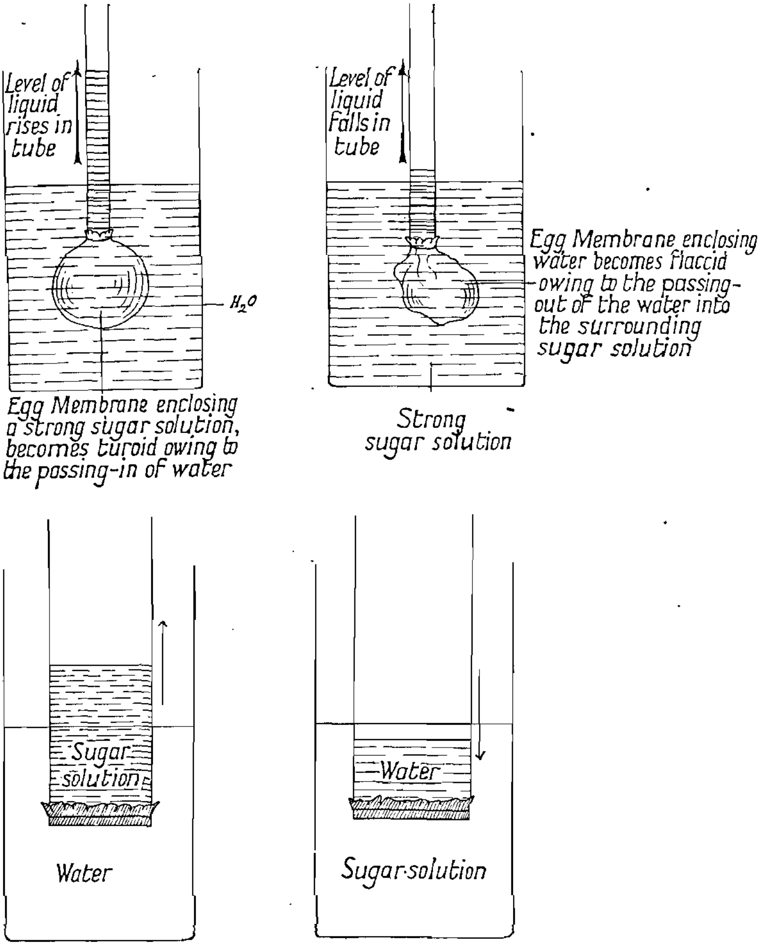
Level of liquid rises in tube
H_2O
Egg Membrane enclosing a strong sugar solution, becomes turgid owing to the passing-in of water
Level of liquid falls in tube
Egg Membrane enclosing water becomes flaccid owing to the passing-out of the water into the surrounding sugar solution
Strong sugar solution
Sugar solution
Water
Water
Sugar-solution

FIG. 5.

Endosmosis.
The level of the liquid in the cylinder rises, owing to the passing-in of water.

Exosmosis.
The level of the liquid in the cylinder falls, owing to the passing-out of water.

From an actual experiment performed in the laboratory.

Exactly the same sort of thing goes on in a young vegetable-cell. The cell-sap attracts water and weaker solutions from cells situated further back. Such water and weak solutions diffuse readily through the cell-wall, and through the protoplasmic lining, and internal pressure is developed in the cell, which is then in the condition called turgid. The volume of the cell is, in consequence, enlarged, distension taking place to a greater extent vertically than horizontally. But mere distension of an elastic body, like a cell, cannot be called permanent growth, unless such distension be fixed and retained. An india-rubber balloon, for instance, can be readily inflated by blowing in air, and large increase in volume will, for the moment, occur, but all the increase in volume will again be lost if the air be allowed to escape. Similarly, a turgid cell will shrink and become flaccid if by evaporation or otherwise liquids be withdrawn from it. A cell in this state is said to be in a condition of plasmolysis. If we take the young shoot of a tree when growing vigorously we find that it is generally erect, its comparatively rigid condition being due to the distended condition (turgidity) of its individual cells. But sever such a shoot from the tree, and expose it for a short time to the influence of dry air, and it will rapidly become limp, and droop. The individual cells are now in a state of plasmolysis. It will be noticed, however, that the drooping is most noticeable near the apex, in the region, namely, where the cells still possess thin cellulose walls. Further back, the cells have become lignified, and consequently do not collapse when water is withdrawn. In that region, in fact, they have passed into the condition of permanent woody tissue.

Lignification

It is therefore necessary to ascertain the process by which the distended cell, with its cellulose wall, becomes possessed of a wall which is lignified and therefore rigid. To appreciate the change we have to call in the assistance of Nägeli's theory, which postulates that the cellulose cell-wall is composed of groups of molecules called micellae (Fig. 6). Such a theory harmonizes well with our conception of matter in general, which, it is now recognized, is always composed of molecules of definite shape and constitution. These molecules, however, are not in actual contact with each other, being kept apart by the all-pervading substance called ether. In the case of a vegetable-cell the micellae that compose its wall are kept apart by water and watery solutions, the water that saturates a cell-wall being called water of imbibition, to distinguish it from the water which is present in the cavity (lumen).

When the cell is in a distended (turgid) condition fresh additions of cellulose are made to the already-existing cellulose of the cell-wall. This takes place by the creation, through the agency of the protoplasm, of new micellae, which are deposited between the older micellae. Growth of this kind is distinguished as growth by intussusception. It can be clearly presented to our minds if we compare a cellulose cell-wall to a wall that has been constructed of children's bricks, and imagine that the individual bricks are micellae. Such a wall can be heightened in two

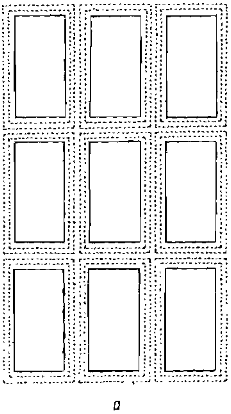

FIG. 6.—9 "Micellae," each surrounded by films of imbibition water (represented by dotted lines) which cause their separation.

ways, namely, by piling fresh bricks on the top, or by easing up the wall along a joint and pushing fresh bricks into the space thus made. In both cases the wall would gain equally in height, and the latter method of procedure is analogous to growth by intussusception.

It is well known that in passing from the fresh condition to a condition of dryness wood shrinks.

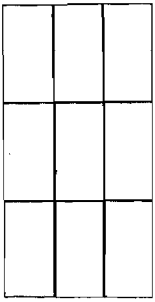

FIG. 7.—The same 9 "Micellae" in close contact, the water of imbibition being lost.

This is entirely due to the extraction of imbibed water, that is to say, water which has been present between the micellae of the cell-walls (Fig. 7). Similarly, if a piece of wood is perfectly dry and is brought into contact with water it increases in volume by the entrance of water between the micellae and the forcing of them apart. This will take place even if a piece of dry wood is exposed to the air, because there is always moisture in the air, and this water is deposited between the micellae. It is well known that this increase in the volume is usually accompanied by great pressure, so much so, in fact, that if dry wood blocks are driven into a stone and subsequently wetted, the mass is ruptured. This fact is taken advantage of by quarrymen in detaching blocks of stone from the face of a rock. It is owing to the shrinkage of wood that cracks form in trees in the process of drying, and, in order to avoid these cracks, timber is either not dried at all or very slowly dried. Timber is very often conserved by being put into " ponds," when it will keep for an indefinite period without shrinking. Timber which is dried in the bark does not shrink so much or so quickly as timber which is peeled. But, of course, drying in the bark may mean an attack of fungi or insects, and these may do more harm than a few cracks.

A young vegetable-cell, when in a fully distended condition, may be compared to an oblong room in a brick house. The walls of the room correspond to the walls of the cell, and the bricks may be compared to the micellae. And just as the bricks are kept from contact with each other by the enveloping layer of mortar, so are the micellae separated by the water of imbibition.

The layer of plaster on the inside of the room corresponds to the protoplasmic lining in the vegetable-cell. In a room, too, there are apertures (windows and doors) which may be compared to the pits in a cell, and the glass in the windows finds its counterpart in the primary cell-wall that acts as a closing membrane in the middle of the pits.

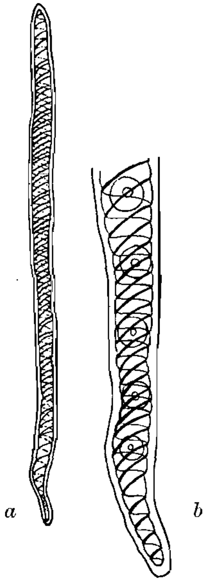

Fig. 8.—*a*, Yew Tracheid, with double spiral thickening; *b*, a portion of a Tracheid, × 400.

While the cell-wall is stretching, new material is being added by intussusception, but when the cell has attained to its full size and final shape, additions to the cell-wall are chiefly made in another way. Cellulose is now deposited as a series of thin layers on the surface of the original (primary) wall, and the wall of the cell rapidly undergoes a thickening process. This is known as growth by apposition. In a wood-cell this secondary layer is much thicker than the primary one, and is often deposited in a spiral fashion (Fig. 8). The process of thickening takes place further back in the shoot than the zone of cell-elongation, the region where it is most active being designated as the zone of cell-wall thickening or internal development.

Concurrently with the formation of the secondary cell-wall, it, and the primary wall, undergo lignification. This process consists in the deposition of certain substances (coniferin, vanillin, wood-gum, etc.), which are collectively called lignin, in the primary and secondary cell-walls. It displaces a certain amount of the water of imbibition, and is deposited as a thin encrustation around the cellulose micellae. When the process has been completed the cellulose is entirely obscured, and the wall no longer gives the cellulose reactions.

Of these two walls, the primary and secondary, the former is much the more lignified, the cellulose in the latter, in fact, being sometimes hardly obscured by the encrusting lignin (e.g. *Pinus Strobus*).

The innermost part of the thickened wood-cell wall generally differs somewhat from the main mass of secondary thickening. It is frequently not so much lignified, giving the reaction for cellulose quite distinctly, and is known as the tertiary wall or the limiting layer.

Pits

The secondary wall of a wood-cell is never deposited equally over the whole surface of the primary wall (Fig. 9). At numerous points on the primary wall no secondary thickening takes place, and such unthickened places are exactly opposite similar unthickened areas in adjoining cells. In this way passages called pits are formed between neighbouring cells, but these pits, instead of being open tubes, are divided transversely by the primary cell-wall, which, in this connexion, may be called a closing membrane. In the kind of cell (the tracheid) that forms the bulk of the wood of conifers, and which is common also in the wood of broad-leaved trees, the pit is of the kind called bordered. Such a pit is produced by each successive layer of the secondary thickening over-hanging more and more the part of the primary cell-wall that ultimately becomes the closing membrane of the pit. The central portion of this closing membrane becomes somewhat thickened, and constitutes the torus, and this, when pressure is greater on one side than the other, is closely pressed against the opposite aperture. Seen on ground plan a bordered pit shows two more or less concentric circles, the inner, however, owing to the spiral deposition of the secondary thickening, being often elliptical in outline. The outer circle corresponds to the extreme area of the cavity of the pit, while the inner circle represents the aperture into the cell lumen. When viewed in section a bordered pit is lenticular in outline, with apertures on each side at the point of greatest width, the closing membrane, with its thickened torus standing in the middle, or lying against one side.

The torus acts as a valve, being capable of regulating the passage of liquids and air, no matter from which side the pressure may come. Were pressure much greater on one side than the other, the closing membrane, if not strengthened by the torus, would be forced into the aperture of the bordered pit and ruptured. While the torus, and the delicate closing membrane to which it is attached, play an important part in regulating the movement of liquids and air, they do not altogether stop their passage. When the torus is pushed to one side, the closing membrane is necessarily stretched, and when in this

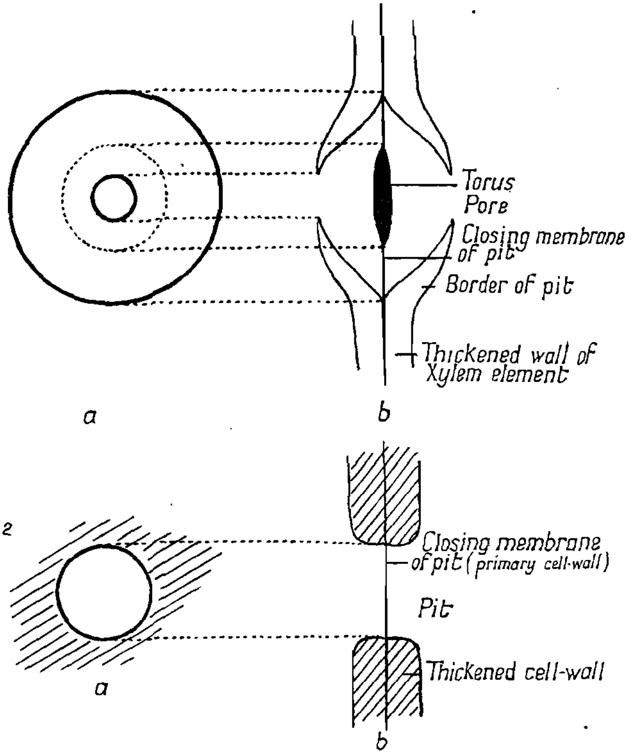
Torus
Pore
Closing membrane of pit
Border of pit
Thickened wall of Xylem element
a
b
2
Closing membrane of pit (primary cell-wall)
Pit
Thickened cell-wall
a
b

FIG. 9.

1. Bordered pit, as in tracheid of *Pinus* (Diagram.). *a*, surface view ; *b*, section.

2. Simple pit, as in endosperm cell of *Ornithogalum* (Diagram.). *a*, surface view ; *b*, section.

condition the filtration of liquids through this distended membrane is probably facilitated. It is also to be noted that the torus, in many cases, is of such a form as to permit the easier movement of water through the aperture of the bordered pit. In the Cedar the torus has a scalloped margin (Fig. 101), while in Spruce it is radially fluted ; in such cases it may be assumed that the percolation of liquids is assisted in the same way that a corrugated filter assists work in a chemical laboratory. In dry pine wood, the torus is always found to be lying against one of the apertures of the pit, but if fresh wood be examined it will be found that in the alburnum (sap wood) the torus exactly bisects the pit, whereas, even in fresh duramen, it lies against one side, and in this position it may be permanently fixed.

Pits, whether simple or bordered, are the form most usually associated with the thickened parts of the primary wall of a wood-cell. But the secondary thickening may be laid on irregularly in other ways. Sometimes it takes the form of a spiral (Fig. 103), a condition of things that is conspicuous in the tracheids of the Yew and Douglas Fir (Fig. 100), and less so in the Spruce. Even in wood that does not, under ordinary conditions, show spiral thickening (e.g. *Pinus silvestris*), this condition reveals itself when fungus mycelia are at work in the tissues. Some mycelia dissolve and remove cellulose (e.g. *Polyporus Schweinitzii*), others leave the cellulose untouched but remove lignin (e.g. *Trametes Pini* and *T. radiciperda*). Such attacks induce cracking in the residues of the secondary cell-walls, when their spiral structure becomes apparent.

Tests for Cellulose and Lignin

In microscopic work the usual agent to prove the presence of cellulose is chlor-zinc iodine, which produces a violet colour, the lignified cells showing up yellowish brown. There are many tests for lignin, one of the best being a solution of aniline sulphate which produces a bright yellow colour in lignified tissues. Another test for lignin is to dissolve a trace of phloroglucin in alcohol, and having immersed the wood section in the solution it is placed on a microscope slide and provided with a cover glass, after which hydrochloric acid is allowed to diffuse in from the side and the lignified tissue is coloured violet red.

Vast quantities of wood are annually made into paper, the process depending on the removal of the lignin by some solvent, usually calcium sulphite. To effect this removal the wood is first reduced to small thin chips, which are then boiled in the solution under pressure, the result being that the lignin, which encrusts the micellae, is dissolved and the pure cellulose cell-walls remain behind. The mass is then pressed into sheets and put on the market as wood pulp or wood cellulose, and from it most of the paper on which newspapers and many books are printed is made. In the laboratory when one wants to study isolated wood-cells one subjects a thin section to maceration. The solution usually employed consists of a mixture of Chlorate of Potash and Nitric Acid (Schultz's solution), which dissolves the lignin and leaves the cells detached from each other.

Buds

The extreme apex of a shoot or branch, comprising as it does delicate thin-walled cells, requires to be guarded from the severe cold of winter, and to effect this the growing point is generally protected by a bud (Fig. 10). The bud consists of scales, which are metamorphosed leaves or stipules changed from their ordinary form for the purpose of affording protection to the delicate cells. In some buds these scales are very numerous, and this is especially the case in trees which cease to grow in length early in the season, *e.g.* Beech (Fig. 11), Oak, Hornbeam, Horse Chestnut, Lime, Scots Pine, Spruce, etc.; whereas in the case of trees which continue to grow far into the summer or autumn the bud consists of but few scales, *e.g.* Birch, Alder, and Willow (Fig. 12), the last mentioned, in fact, having only a single scale-cover over the young leaves in the bud, but although apparently only a single scale it really consists of two fused together along the edge. In the case of at least

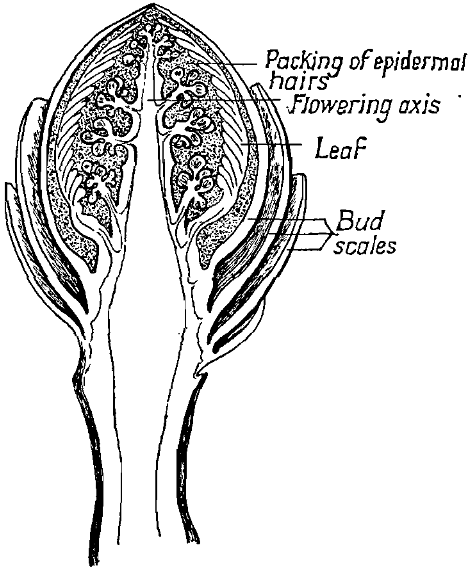

Fig. 10.—L.S. through a flower-bud of horse-chestnut, just about to open. (Slightly diagrammatic for clearness, but drawn from actual specimen.)

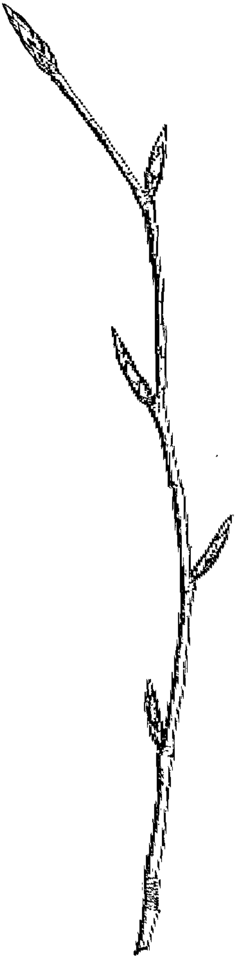

FIG. 11.—Beech Buds.

one British ligneous plant, *Viburnum lantana*, there are no scales, and the bud is said to be naked (Fig. 13).

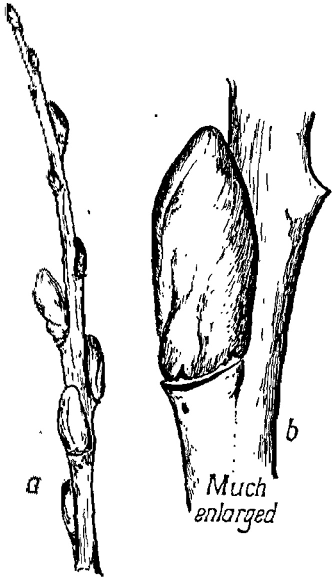

FIG. 12.—Willow Buds.

The scales of Horse Chestnut, Maple, Cherry, Ash, and most conifers, consist of modified leaves; whereas in the case of Beech, Oak, Elm, Lime, Hornbeam, Poplar, Willow, Alder, and *Platanus*, the scales are modified stipules (Fig. 14). Stipules are foliar organs situated at the base of the stalk

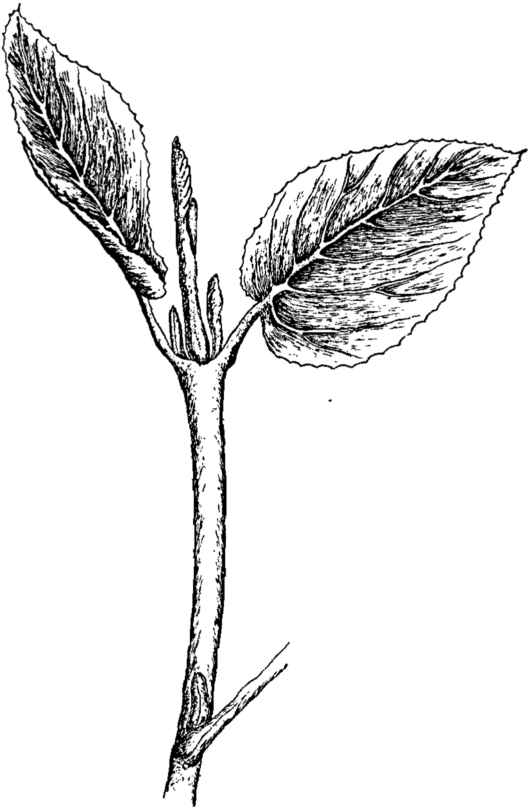

Fig. 13.—*Viburnum lantana*, naked buds. (The buds have a "mealy" appearance due to protective epidermal hairs.), (Actual specimen.)

(petiole) of true leaves, and that the bud scales of the trees just mentioned are stipules is evident from the fact that when a young shoot of one of the species has recently emerged from the bud it will be found that the bud scales remain adhering close to the base of the petioles of the leaves.

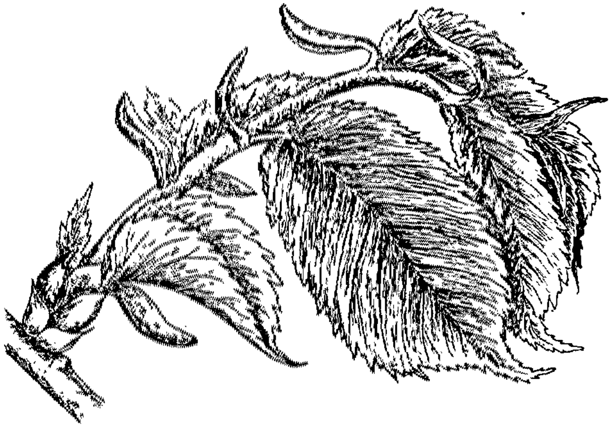

FIG. 14.—Elm, with stipular bud-scales *in situ*.
(From actual specimen.)

Shortly after the shoot has fully expanded, the stipular scales fall from the tree, and where Elms, for instance, line a roadway, it will often be seen in the month of May that the surface of the ground is thickly covered with these bodies. Such stipules are called caducous or fugacious, but in the case of many plants the stipules persist and are practically as long-lived as the true leaves, as, for instance, in many Willows and in Hawthorn (Fig. 15) and *Platanus*.

In the case of a great number of trees growth in length is confined to a very short period, often only a matter of a few days, and then the shoot proceeds to protect its growing point against the cold of winter by forming what is called a winter bud. This, although formed so early as the month of May or June, will normally remain quiescent until the beginning of the following growing season; but in some cases these buds are stimulated to develop in the same season in which they have been formed, and then we have the condition of things known as Lammas shoots, namely, fresh shoots produced about the time of the year called Lammas, which falls in the month of August. The Oak is a tree specially liable to form Lammas shoots, more particularly if the weather is wet in the latter half of July or the beginning of August. Under these circumstances it will be found that the dark green foliage of this tree becomes intermixed with foliage of a much paler green, due to the production of fresh shoots and fresh leaves. Similarly, flower buds which normally will remain dormant until the following season sometimes burst out in the autumn, and give rise to the phenomenon known as autumn

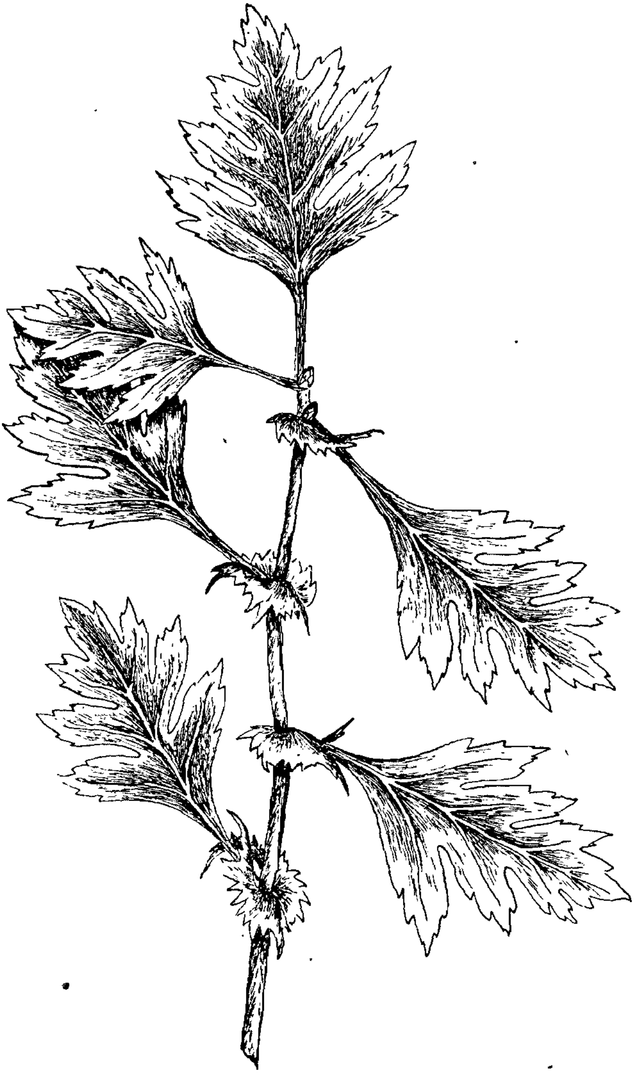

FIG. 15.—A shoot of Hawthorn, in November, to show persistent stipules. (From actual specimen.)

flowering amongst fruit trees ; pears and apples often showing this condition of things.

The production of fresh shoots in late summer or autumn is very common in nursery stock, and is highly undesirable, inasmuch as such shoots seldom ripen properly before winter sets in, so that they are generally killed by frost, and the young tree is misshapen and reduced in value. Amongst conifers, the Douglas Fir is specially apt to show this "second growth," as it is called. Frequent transplanting in the nursery, by restricting growth, is the best preventive. Cutting many of the roots by means of a spade in the month of July is also an effective procedure.

Terminal and Axillary Buds

The majority of the buds on a shoot or branch are either terminal or axillary. A true terminal bud occupies the end of a shoot, and characterizes most conifers, and is also the condition of things in the Sycamore, Oak, Poplar, Horse Chestnut and Ash. The branching associated with true terminal buds is known as monopodial, racemose, or indefinite (Fig. 23). The majority of hardwood trees, however, have no true terminal bud, the bud that appears to be at the end of the branch or shoot being really an axillary bud which is functioning as a terminal bud (Fig. 16). That the bud at the end of a branch is often not a true *terminal* bud is evident from the fact that one finds a leaf or leaf scar on one side of such a bud, and not infrequently the withered apex of the branch which has dried at the end of the season and remained attached. The kind of branching associated with the absence of true terminal buds is known as sympodial, cymose, or definite, and characterizes the Lime, Hazel, Elm, Hornbeam, Willow, Birch, Beech, Spanish Chestnut, etc.

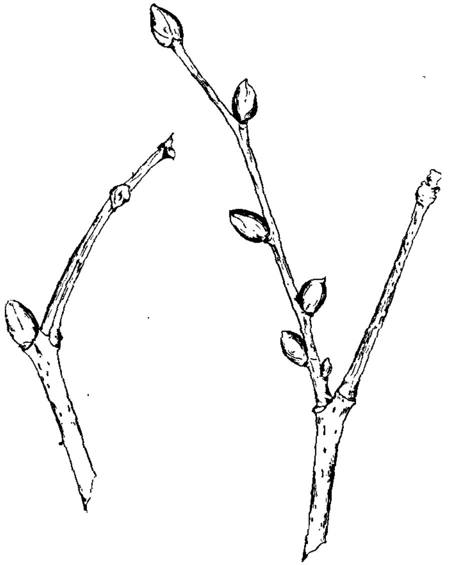

FIG. 16.—Twigs of Lime, × 1, from actual specimens, showing the sympodial growth, and " dead ends " of twigs.

The actual height-growth made in a year depends on a number of factors, such as species, the character of the season, the quality of the soil, the altitude above sea-level, and the age of the tree. Taking any particular species, say Scots Pine, we find that, where the quality of the locality is good, the figures will run something as follows :

For the first 10 years, the average annual height-growth will be about 12 inches.
For the next 10 years, the average annual height-growth will be about 20 inches.
For the next 10 years, the average annual height-growth will be about 18 inches.
For the next 10 years, the average annual height-growth will be about 13 inches.
For the next 10 years, the average annual height-growth will be about 11 inches.

So that by the time the tree has reached the age of 50 years it will have attained a height of about 62 feet. Dividing this by 50 we get a mean annual height-growth of about 15 inches. But it will be seen that this is not reached in the first period of 10 years nor in the period beyond the thirtieth year, whereas it is largely exceeded in second and third decennial periods. In other words, in the case of the Scots Pine (a light-demanding species), growing in a good situation, the maximum annual growth in height is reached fairly early, and from that point it steadily declines, until when the tree is 100 years old it only gets taller to the extent of an inch or two each year.

If we examine a Scots Pine growing under much less favourable conditions, the figures will show something like the following series:

For the first 10 years, the average annual height-growth will be about 5 inches.
For the next 10 years, the annual average height-growth will be about 6 inches.
For the next 10 years, the average annual height-growth will be about 7 inches.
For the next 10 years, the average annual height-growth will be about 8 inches.
For the next 10 years, the average annual height-growth will be about 6 inches.

Such a tree, therefore, has only reached a height of about 27 feet by the fiftieth year, which means a mean annual height-growth during the period of little more than 6 inches. It will be noted, too, that the period of maximum growth in height is not reached till 10 years later than in the other case, and that it is only 8 inches as against 18.

If we now examine corresponding figures for a shade-bearing species, say the common Silver Fir, we shall find that growth is slow in youth, and that the culminating period of maximum height-growth is not reached till later than is the case with a light-demanding species, such as the Scots

Pine. Thus for a Silver Fir growing under really good conditions :

For the first 10 years, the average annual height-growth will be about 4 inches.
For the next 10 years, the average annual height-growth will be about 7 inches.
For the next 10 years, the average annual height-growth will be about 10 inches.
For the next 10 years, the average annual height-growth will be about 15 inches.
For the next 10 years, the average annual height-growth will be about 18 inches.
For the next 10 years, the average annual height-growth will be about 15 inches.

Here, then, while the growth in height at the maximum period is the same, 18 inches, as in the case of the Scots Pine, this stage is not reached till 20 years later.

It is interesting to note that the annual growth in length of a shoot is a sort of epitomized history of the height-growth of a tree throughout a long series of years (Fig. 17). It will be seen that towards the base the internodes are short, corresponding to the comparatively short annual height-growth of a tree in the early stage of its existence. Then, the internodal intervals reach their maximum and gradually decrease exactly as in the case of a tree, where the annual height-growth progressively declines from the culminating point.

Axillary buds (Fig. 18) are formed in the angle

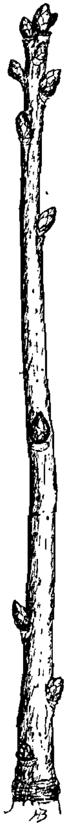

FIG. 17.—An Oak Twig showing "spacing" of the Buds.

between the leaf stalk and the shoot, and while in many cases they stand symmetrically in this angle, they occupy a position somewhat to one side in the case of the Beech, Lime, etc., and

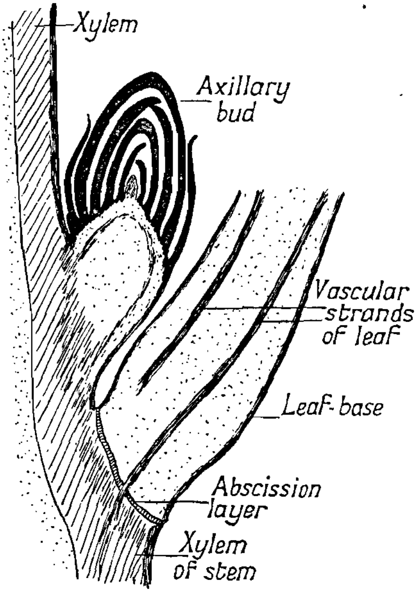

FIG. 18.—Diagrammatic section (nearly median) through an axillary bud and leaf-base of Sycamore. (Actual specimen.)

sometimes they are not in the angle at all, but are buried in the petiole or leaf stalk itself, and consequently cannot be seen until the leaf has been pulled off. This condition of things characterizes *Robinia*, *Platanus*, and *Cladrastis tinctoria* (Fig.

19). Usually an axillary bud is sessile, that is to say it has no stalk, but an exception occurs in the Alder, where the bud is raised on the end of a short but distinct stalk (Fig. 20). In addition to the axillary bud, it not infrequently happens that there are additional or accessory buds close to the axillary bud, and such accessory buds may occur above the axillary bud, in which case they are said to be superior, an example of which is furnished by the Hornbeam; or they may be below the axillary bud, in which case they are

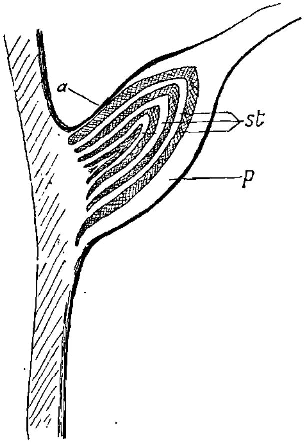

FIG. 19.—Diagrammatic L.S. of a Plane-bud, showing its investment by the petiole-base, *p*. At *a* is the thin part of the petiole-base which ruptures before the leaf-fall. *st* are the cap-like stipules forming the bud-scales. The leaf-rudiments (not shown) are at the bases of the innermost stipules. (Actual specimen.)

said to be inferior, examples of which occur in the Ash, and in the common Elder (Fig. 21). If a stout shoot of such trees be examined the inferior accessory bud will be easily seen immediately

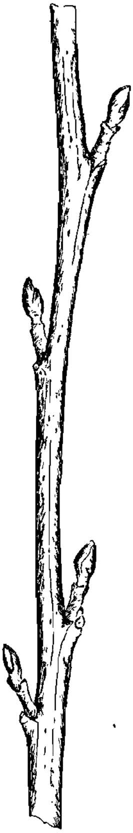

FIG. 20.—Stalked Buds of Alder. (Actual specimen.)

below the main axillary bud, and if the shoot be cut over and the axillary bud removed, it will be found that the accessory bud will grow out to produce a shoot in the same or the following season. Sometimes the accessory bud is neither above nor below the main axillary bud, but is situated at one side, as in the case of the Hawthorn, where there are two accessory buds, one on each side of the main axillary bud, the latter being often converted into a thorn (Fig. 22). In the case of the Hawthorn, therefore, the thorn is a modified bud, and as a bud may

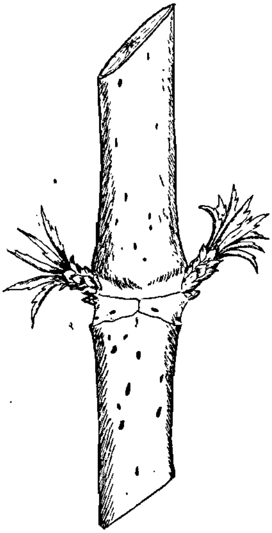

FIG. 21.—Inferior Accessory Buds of Elder. (From actual specimen.)

produce a shoot, the thorn may be said to be a modified shoot. In *Robinia* the thorn is a modified stipule; in the Gooseberry it is an outgrowth of the pulvinus or cushion on which the leaf stalk is fixed; while in the Barberry it is a modified leaf.

The appearance of the buds is a useful aid in the identification of deciduous trees and shrubs in winter; thus, for example, Norway Maple and Sycamore are almost indistinguishable as regards habit, colour of bark, etc., but can at once be recognized by the fact that the buds of the Sycamore stand clear of the shoot, whereas those of the Norway Maple are closely pressed against the stem (Figs. 23 and 24).

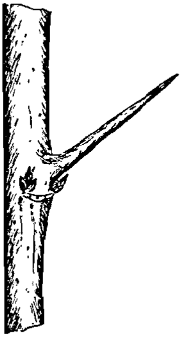

FIG. 22.—Hawthorn. Axillary bud converted into spine. Lateral accessory buds. (From actual specimen.)

While it is the rule that each leaf of a produce a shoot, the thorn may be said to be a modified shoot. In *Robinia* the thorn is a modified stipule; in the Gooseberry it is an outgrowth of the pulvinus or cushion on which the leaf stalk is fixed; while in the Barberry it is a modified leaf.

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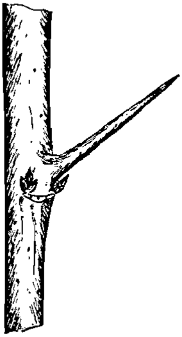

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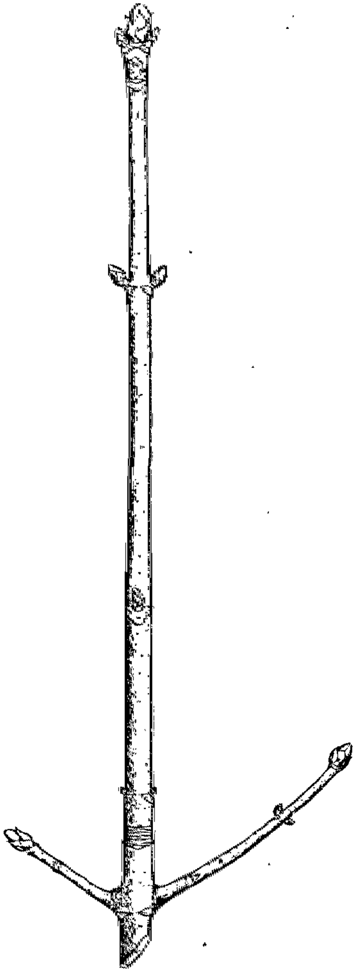

FIG. 23.—Sycamore. Monopodial Branch-system. Prominent buds. (Actual specimen, × ½.)

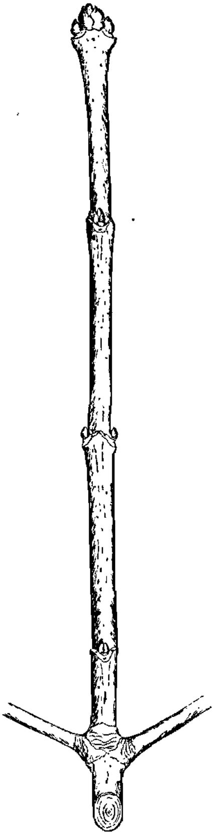

FIG. 24.—Norway Maple.

dicotyledon has an axillary bud in the angle that it forms with the shoot, it is a rule to which there are numerous exceptions. Thus the lowest leaf or pair of leaves on a normal Beech shoot have usually no such buds, while none of the leaves on a dwarf shoot of the Beech possesses axillary buds. Normally also the two lowest leaves of Hornbeam, Lime, and Birch are devoid of lateral buds, and in the common Alder a similar condition of things prevails in respect of the four lowest leaves.

In the case of conifers many leaves possess no axillary buds. Thus on a shoot of Spruce (*Picea*) it will be found that there are no buds associated with the lower leaves; then there are usually some buds near the middle of the shoot, and again towards the apex. In the Yew, buds appear in quite irregular fashion on the shoot.

In the Pine the dwarf shoots (bifoliar spurs) are situated in the axils of scale-like leaves (Fig. 26).

Shoots

Terminal and axillary buds may develop into flowers, normal shoots, or dwarf shoots, or they may remain quiescent, when they are known as dormant eyes. Normal shoots are the ordinary shoots of the tree, the sum of whose annual growth represents the total vertical and lateral development of the crown of the tree. But many shoots, instead of extending normally, grow only

an inch or so, when the winter bud is again formed, and next year the same slow growth is continued. Such shoots are known as dwarf shoots in the case of forest trees, or as spurs when

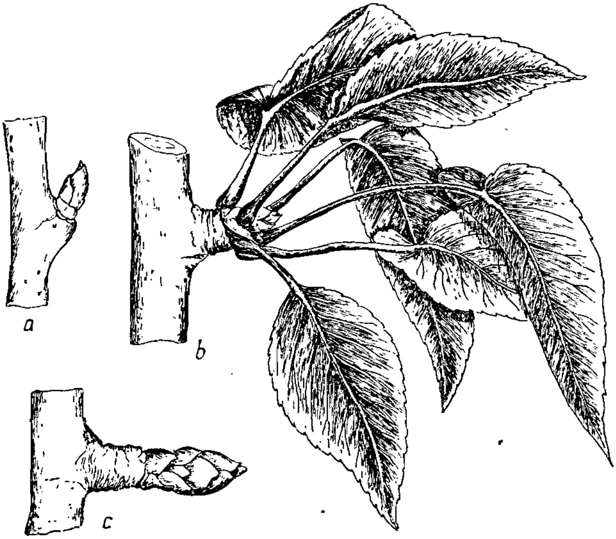

FIG. 25.—A Pear Shoot. (After Percival.)

a. A piece of last season's shoot of pear-tree, with bud as seen in autumn.

b. The same the following midsummer; the bud has now given rise to a "spur" or dwarf-shoot, bearing leaves, and terminated by a fruit bud.

c. The same, after leaf-fall, in autumn.

they occur on fruit trees (Fig. 25). In many instances they bear a large part of the total foliage of the tree, and in the case of certain fruit trees they produce the whole of the blossom. Dwarf shoots produce the whole of the green foliage in the case of all Pines beyond the seedling stage; the so-called bifoliar spurs of the Scots Pine, for instance, being really dwarf shoots consisting as they do of two leaves with a small bud in

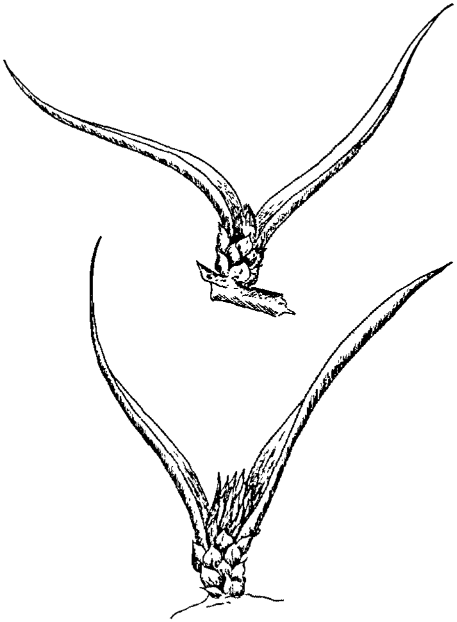

Fig. 26.—Partly "Stimulated" Pine-buds. × 1

the angle between them (Fig. 26). That these bifoliar spurs are really shoots becomes apparent if a vigorous young stem is cut over near the apex, when it will usually be found that many of the buds between the leaves are stimulated to

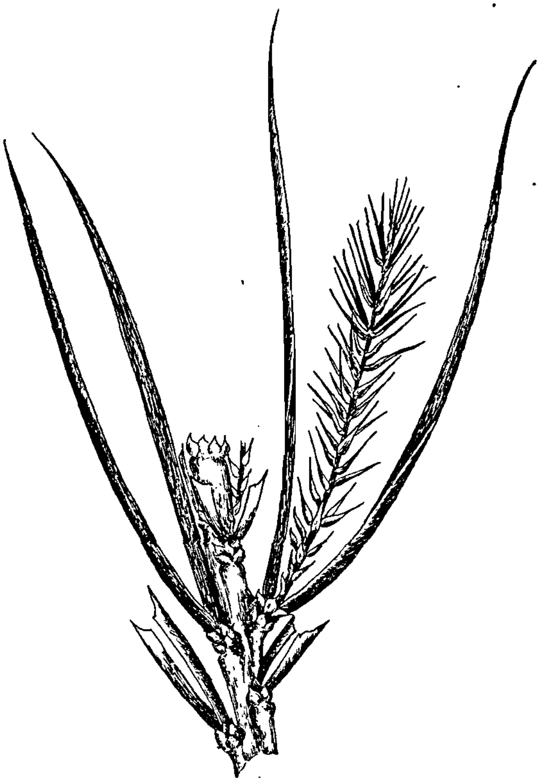

FIG. 27.—" Stimulated " Pine-buds.

develop and to grow out to form shoots (Fig. 27). The rosettes of the Larch and Cedar are also examples of dwarf shoots; while all dicotyledonous trees show them in abundance. When a Pine casts its leaves it really sheds dwarf shoots, and the same is true with the deciduous Cypress (*Taxodium distichum*), the leaves not falling off singly, but attached to twigs. Even in the case of dicotyledonous trees one not infrequently finds dwarf shoots being cast off, as for instance in the case of the Oak, where in late autumn one will often find the ground underneath covered with twigs three or four inches long with rounded ends, not ragged as would be the case if the twigs were broken off by animals such as squirrels, or by the wind. This shedding of shoots, as distinguished from the shedding of individual leaves, is known as cladoptosis.

While the majority of buds unfold every year to produce flowers or normal shoots or dwarf shoots, a considerable proportion in the case of dicotyledonous trees do not unfold at all, but remain latent, and are known as dormant eyes (Fig. 28). If a branch of, say, Willow, an inch or so in thickness, be examined, many of these dormant eyes will usually be found upon the surface of the bark, and that they are quite capable of unfolding and producing shoots is evident from what takes place should the tree be cut over above these dormant buds. Although such buds do not unfold under normal circumstances, the fibro-vascular bundle that connects them with the stem or branch must elongate every year, or otherwise the bud would soon be pushed off or be enveloped by the growing bark of the tree. As a matter of fact, the fibro-vascular bundle extends in length each year to an extent that corresponds exactly with the radial growth of the branch or stem. Sometimes the bud does become detached from the fibro-vascular bundle, and in the case of the Beech it

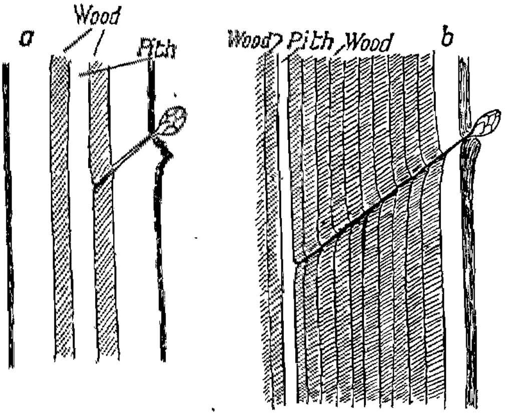

FIG. 28.—Diagrams adapted from Marshall-Ward.
a, L.S. of twig 1 year old, with dormant bud. *b*, L.S. of branch 10 years old, showing dormant bud.

is capable of continuing to grow by drawing nourishment from the tissues of the cortex, when it swells up into a round woody body known as a spheroblast, many of which can often be seen loosely attached to the bark of a Beech tree.

Light-Growth

Under certain kinds of stimuli the dwarf shoots of a dicotyledonous tree will grow out to produce normal shoots, and this occurs in the case of a wood which has been thinned after growing up in close canopy. The result is specially conspicuous where a forest is approaching the end of its rotation, and where a very heavy thinning, known as a seed-felling or a felling-for-light, is made. It is well known that under such circumstances the trees that are left standing make extraordinarily rapid growth, such increased growth being due to a combination of causes. In the first place the admission of a largely increased amount of light to the crown stimulates dwarf shoots to grow out like normal shoots, with the result that in a few years the area of foliage of the tree is greatly increased. This enables the tree to fix an increased amount of carbon from the air, and this ultimately takes the form of increased production of wood. Then, again, the large expanse of foliage means that an increased quantity of water containing nutrient solutions is drawn up from the ground, and so the tree is more liberally provided with mineral and nitrogenous food. The removal of a large proportion of trees also means that the competition for nourishment between those that remain is greatly

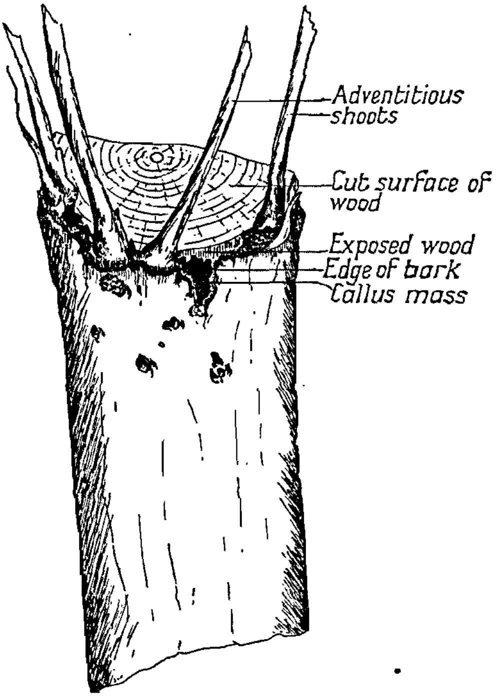

FIG. 29.—The base of a poplar-stem which was cut down and from which axillary buds were removed. At the cut edges, between the bark and wood, a callus produced adventitious shoots.

reduced, so that, other things being equal, they are in a position to absorb more nourishment. Also the admission of an increased amount of light and of rain-water to the surface of the ground results in the accelerated decomposition of the leaf mould, or, as it is called, forest humus, covering the surface of the ground, and the decay of this substance means the liberation of nutrient materials, both mineral and nitrogenous, which become available for the use of the trees that are retained. The result of the combination of all these causes is the accelerated formation of wood, to which the term light-growth is given.

The kinds of buds that we have hitherto been considering arise at definite parts of the stem and branches, true terminal buds appearing at the end, and lateral buds being formed in the axils of the leaves. These buds, whose position is predetermined from the beginning, are collectively known as proventitious buds; but, in addition to these, one may have another kind of bud, known as an adventitious bud, that originates by accident or adventitiously, and chiefly in the so-called callus tissue that forms round the edge of a wound (Fig. 29). Such adventitious buds are chiefly confined to dicotyledonous trees, and often appear at the margin of the stool of, for instance, an Oak which has been cut over in the process of coppicing. When Oak coppice is felled, fresh shoots rapidly sprout from the stump, those arising from the callus on the edge of the stool being adventitious shoots that have sprung from adventitious buds; while those springing from the bark of the stool itself, somewhere between the cut surface and the level of the ground, have for the most part their origin in dormant eyes, which have remained quiescent and inconspicuous until stimulated to development by the felling of the stem. When Oaks are allowed to grow up in dense canopy until they are forty or fifty years old the stems, as a rule, are well cleaned, and in their lower parts are destitute of living shoots or branches. But if about middle life the Oak wood is heavily thinned, it generally happens that a considerable proportion of the stems that remain become covered with a more or less dense growth of young shoots which have originated in dormant eyes that have been stimulated to activity by a large accession of light. Such shoots are known as epicormic branches, or are sometimes called water-shoots. Their presence generally indicates unhealthy growth of the tree on which they form, for the reason that they tap the ascending stream of water and plant food that rises from the soil, and prevent its full flow to the crown of the tree, which, on account of being thus restricted in respect of its supplies of water, frequently becomes unhealthy, and may die in parts (stag-headed).

Adventitious buds often appear on the roots of trees, and give rise to root suckers, as for instance in the case of English Elm, Abele tree (*Populus alba*), Balsam Poplar, and the Locust tree (*Robinia pseudacacia*), where they spring up often quite a long distance from the stem.

Growth in Thickness

Growth in thickness of a stem is entirely due to the activity of a zone of cells situated between the wood and what is popularly called the bark. This layer consists of cells that are living and capable of subdividing, and thus of increasing in numbers. The cells which are produced on the inner surface of the layer become wood, while those on the outer side become cortex, and the collective aggregation of the latter is the substance that is popularly called bark (Fig. 30). This zone of cells is known as the cambium, which during winter is inactive, but during the growing season is producing new wood and new cortex. In this country, growth in thickness, that is to say cambial activity, usually begins in the first half of May, the start being made in the upper part of the stem and in the branches, growth in thickness not usually commencing in the lower parts of the stem till a little later. The activity of the cambium depends to a large extent upon its temperature, and this again is chiefly dependent upon the temperature of the air. The upper part of a stem is covered with thinner bark than the lower part, and, moreover, the top of the tree is more fully exposed to the sun's rays, so that the necessary degree of heat is attained sooner towards the top of a tree than towards the foot. The temperature of the stem in its lower part is also kept down by its proximity to the soil, which in the early spring is often

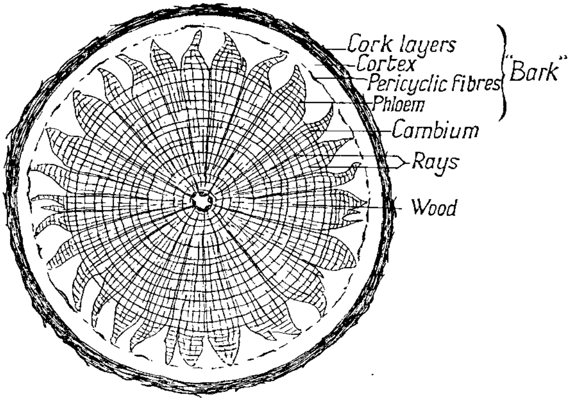

Fig. 30.—T.S. of 14-year-old Twig, × 2, showing the wood, the rays, the cambium and the bark.

very cold. Investigations on *Pinus silvestris* have shown that the beginning of activity in the cambium is hastened by high temperature of the air during January, February, and March, and in such a season a relatively broad ring of wood is formed, which, however, contains a disproportionately large amount of so-called spring wood, and is, therefore, of rather low quality (Fig. 36).

The Temperature of Trees

A large amount of work has been done by Robert Hartig in determining the temperature of stems. He found, for instance, that the temperature of the Beech is higher than the temperature of the Scots Pine or Spruce. This is accounted for by the fact that the bark of the Beech is comparatively thin, and consequently allows the heat of the sun to enter easily to the cambium and the wood. He also found that the temperature of the cambium may be higher than the temperature of the air. Much of his work was done on trees that were in a state of defoliation caused by the Nun Moth. For instance, on August 10, 1891, he examined the temperature on the south side of such Spruces one hundred years old, and found that at 4 o'clock in the afternoon, when the temperature of the air was 23·5° Centigrade, the temperature of the cambium, at a height of one metre from the ground, was 27·8° in the case of normal trees, whereas it was 37° in the case of a tree that had been defoliated. At the height of 8 metres from the ground the respective figures were 28·2° and 32°. The relatively higher temperature of the trees which had been defoliated was due to the fact that (1) there was no foliage to keep off the sun's rays, (2) evaporation from the crown was greatly reduced, and consequently this factor was absent in keeping down the temperature, and (3) that if there is little evaporation from the leaves it means that fresh supplies of water from the ground reach the crown in reduced quantity.

Growth on Stools

Probably most observers have noticed that certain stems when cut over show growth on the stool. This is especially the case with the larch, on an old stool of which a large amount of callus growth will often appear along the line between the wood and the bark. This growth after felling is supposed to be due to the fact that the roots of the tree when felled have been found inarched with the roots of adjoining trees. The consequence is that a supply of the formative material is conveyed from the living tree to the roots of the tree that has been felled, and this material is sufficient to supply the cambium with food enough to make a considerable amount of wood.

Kinds of Cells

The wood which the cambium of conifers forms consists chiefly of one kind of cell, the tracheid, which is characterized by tapering to a point at each end, that is to say it is spindle-shaped, and by being provided with conspicuous bordered pits, which are chiefly on the radial walls. The wood of conifers in some cases contains other kinds of cells, notably parenchyma,

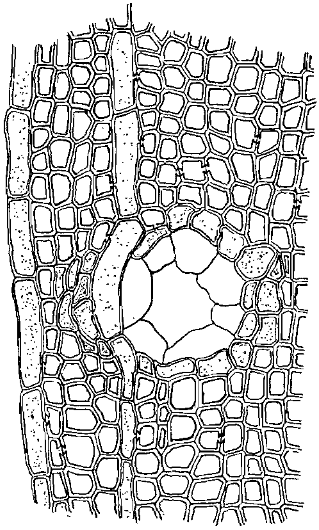

Fig. 31.—*Pinus silvestris.* T.S. Rays and Resin-duct. × 400.

a kind of cell characterized by less tapering ends, thinner walls, and simple pits; such cells are sometimes distributed amongst the tracheids (*Sequoia*), and are always present in greater or less numbers in the medullary rays. If resin ducts are present parenchymatous tissue forms an epithelial lining, in which the resin is produced (Figs. 31 and 32). In the case of broad-leaved trees the wood is more complex, usually containing (1) tracheids similar to those in conifers;

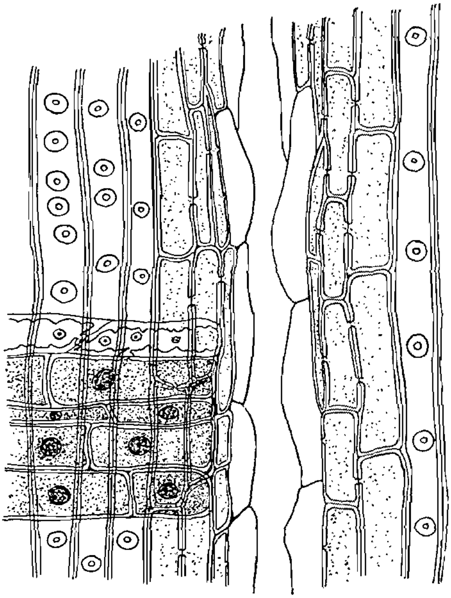

FIG. 32.—*Pinus silvestris*. L.R.S. Ray and Resin-duct in sap-wood. × 400

(2) libriform fibres which, like tracheids, taper at each end, but have usually a smaller internal cavity (lumen) and are not marked by bordered pits; (3) parenchymatous cells, which are thin-walled, not tapering at each end, and provided with simple pits, and vessels (Figs. 33, 34, 35). In broad-leaved trees vessels are met with in every wood ring; whereas in conifers they are entirely absent, except in the neighbourhood of

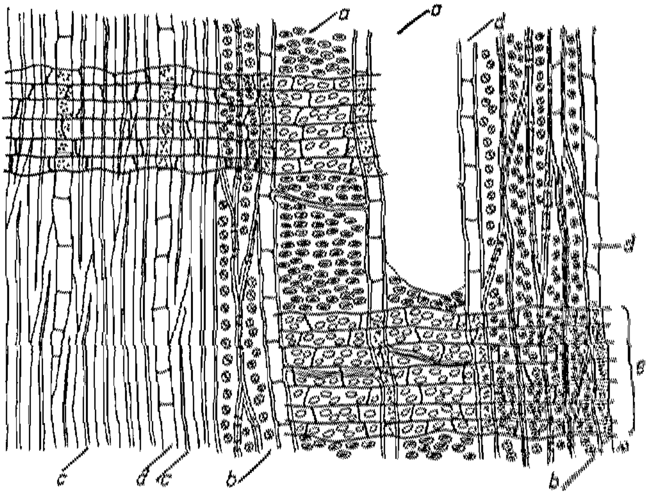

Fig. 33.—L.R.S. Oak, × *circa* 400. To show Fibres, Tracheids, *Vessels, Parenchyma and Rays.*

The details of pitting of horizontal and tangential walls of ray parenchyma and pitting of vertical parenchyma omitted. (Semi-diagrammatic.) *a*, large vessels; *b*, tracheids; *c*, fibres; *d*, xylem parenchyma; *e*, a parenchymatous ray.

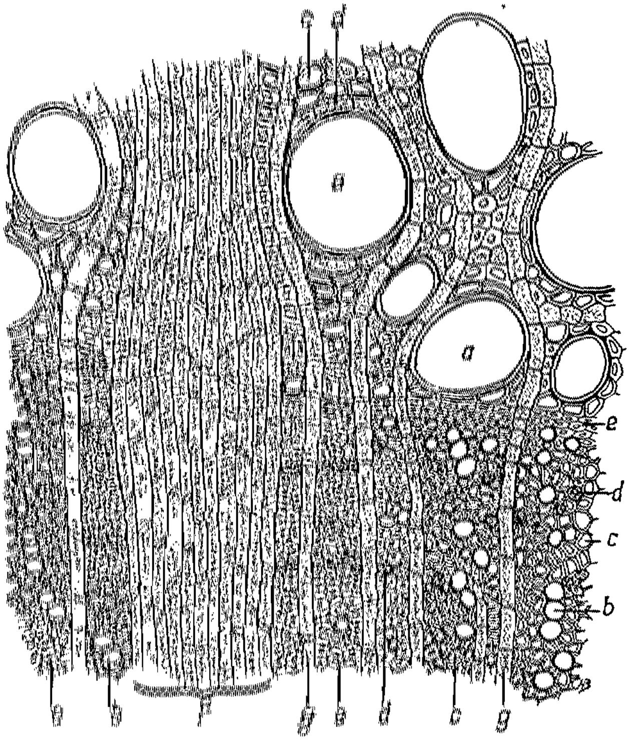

Fig. 31. T.S. Oak, × circa 100. (Semi-diagrammatic.)

a, Large vessels of spring wood; *b*, small vessels of autumn wood; *c*, tracheids; *d*, xylem-parenchyma; *e*, fibres; *f*, a broad ray; *g*, narrow rays.

the pith, that is to say in the wood formed in the first year of growth, the so-called protoxylem.

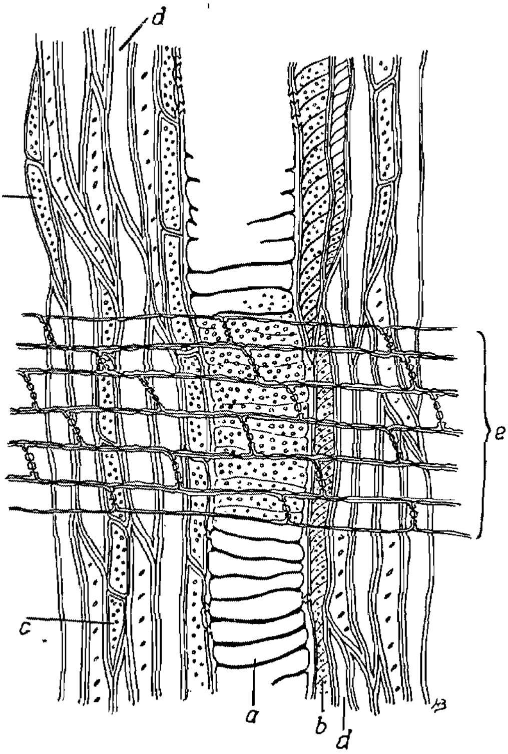

Fig. 35.—L.R.S. Lime.

a, a vessel showing spiral thickening; *b*, a tracheid showing spiral thickening; *c*, xylem parenchyma; *d*, fibres; *e*, a parenchymatous ray.

Vessels are long, open tubes, which have been formed by the disappearance, partial or complete, of the end walls of superimposed rows of cells, and they are so characteristic of the wood of dicotyledonous trees that their presence or absence at once distinguishes such wood from that of conifers (Fig. 34).

The Wood Ring

The wood formed during a season of growth goes by the name of a wood ring, or an annual ring. It consists of two more or less well-defined portions, namely, that which is formed in the early part of the season, the spring wood, and that which is formed later in the season, the autumn wood. These terms are not very happily chosen, because spring wood may be formed in summer, and autumn wood may also be formed before that period of the year has been reached, but if the terms are used to indicate respectively the first-formed and last-formed wood of the annual ring, confusion will be largely avoided. If one examines with the naked eye a well-planed cross-section of coniferous wood, one can see that it consists of concentric rings of paler and darker tissue, and a little more detailed observation will convince us that the paler zone lies on the inside of the annual ring, and is, in fact, the spring wood; while the darker zone lies towards the outer side of the ring and is the autumn wood. If a section be placed under the microscope it will be found that the spring wood consists of tracheids with comparatively thin walls and large internal cavities (lumena); whereas in the autumn wood the tracheids have much thicker walls and are laterally compressed, so much so, in fact, that in the extreme outer margin of the wood ring the internal cavity may have disappeared almost entirely. On account of the thin walls and large lumena, the spring wood is poor in solid substance and is comparatively non-resistant to decay. It is also weaker and incapable of resisting so much pressure as the autumn wood. If the section of a weathered stem be examined, *e.g.* the stool of a tree that has been felled two or three years before, it will be found that the spring wood consists of a series of depressions, while the autumn wood stands out as a series of elevations, proving that decay has progressed further in the former case, thus giving rise to the corrugated character of the cross-section.

Sachs' Theory

Various theories have been advanced to account for the difference in the spring and autumn zones. Of these theories the two best known are those which are associated with the names of Julius Sachs and Robert Hartig. Sachs maintained that the difference in character was entirely the result of difference in pressure on the cambium during the growing season. During winter the cambium is entirely quiescent, and at that time certain natural agents are at work loosening the bark of the tree, that is to say reducing the pressure on the cambium. The winter rains mollify the dead bark tissues, and such softening means that the mantle of bark does not adhere quite so closely to the stem as formerly. Then, again, frost may occur still further to loosen the bark, and the swaying of the stem in the winter gales must also have a similar effect. As a result of all these agencies, so Sachs alleged, the cambium is under comparatively little pressure when it becomes active in the beginning of the following season, and wood formed by the cambium under reduced pressure partakes of the character of spring wood, that is to say it is open and porous, and therefore poor in solid wood substance. As the season advances the cambium is constantly adding to the new wood ring, and in consequence of the formation of wood the cambium is subjected to increasing pressure. In the course of the season the pressure reacts upon the cambium to prevent its forming such porous wood; in other words, the cambium is forced to form cells with small lumena and thick walls. Moreover, these cells being formed under great pressure are much flattened, and are broader in the tangential than in the radial direction.

Hartig's Theory

Hartig's theory proceeds on the assumption that the denser tissue of the autumn wood and the more porous character of the spring wood are the result of the action of various factors of nutrition. According to Hartig the conditions of growth in the spring and early part of the summer are not favourable to the production of dense tissue. His argument may be best illustrated by considering the case of a deciduous tree. In spring or early summer such a tree is producing fresh shoots and leaves, and these make a large demand upon reserve materials stored up in the stem and roots. At that time, therefore, there is comparatively little formative material at the disposal of the cambium. Then, again, the days are short, the temperature low, and the sun's rays of comparatively low intensity, so that the conditions for the elaboration of starch and other plastic substances are not satisfactory. As a consequence the cambium is not placed in possession of full supplies of material from which it can produce solid wood substance, with the result that the cells which it forms at that time are characterized by large internal cavities and comparatively thin walls. As the season advances the formation of leaves and shoots is completed, so that these cease to divert formative materials, which are now available for the use of the cambium. Then, again, the longer days, the brighter sun, and the higher temperature facilitate the production of starch in increased quantity. As a consequence there is in the height of summer and in autumn a much larger supply of formative materials at the disposal of the cambium, which is thus enabled to form denser tissue, that is to say wood with cells whose walls are thick and whose lumena are small.

Hartig's theory, although suggestive from the point of view of nutrition, fails to account for the variation in shape of the cells of the spring and autumn wood, and perhaps the correct explanation may be sought for partly in the theory of Sachs and partly in that of Hartig.

Other Theories

Other theories have been advanced to account for the difference in the character of the so-called spring and autumn zones. It is suggested that the transpiration of water by the tree is much greater in the early part of summer than later on, and that, therefore, the cells formed at that time must be furnished with large internal cavities (lumena), in order that provision may be made for the transference of large quantities of water from the roots to the leaves. Another theory is that spring and autumn wood is the result of the action of different kinds of stimuli on the cambium. Early in the growing season there is a great demand on the part of the tree for water, and this reacts on the cambium and stimulates it to produce elements with large lumena. Later in the season the pressing need of the tree is rigidity, and this similarly reacts on the cambium and stimulates it to produce thick-walled, strong cells, with small internal cavities.

Variations in the Formation of the Wood Ring

Under normal conditions, in a climate with well-marked warm and cold seasons, trees produce one wood ring in the year, so that the number of rings on the cross-section at any point of the stem is usually a reliable index of the age of the tree, that is to say of the number of years that have elapsed since the apex of the tree attained to that particular height. But under abnormal conditions, even in a temperate climate, no ring may be formed in any particular year, or two rings may be formed. The commonest case where no ring is produced occurs towards the base of a tree growing in a very dense wood. Such a tree has usually a long bare stem with a small crown, and as the nutritive materials which maintain the activity of the cambium, and from which this forms wood, come down from the crown, it follows that when the crown is small these substances will be scarce, and may be insufficient to enable the cambium in the lower part of the stem to form wood. It is evident that only a small quantity of material will be elaborated by a small crown, and when this material begins its descent of the stem, it is the cambium nearest to the crown that will be best nourished. Further down, the supplies may be sufficient to enable the cambium to produce a ring, though a narrower one than that which is formed further up; and the further we descend, and thus get away from the source of the supply of cambium food, the less will there be at the disposal of the cambium, until a point may be reached where nothing remains over from which a wood ring may be formed. In such a case the stem will be growing in thickness to the greatest extent in its uppermost parts, to a less extent in the middle region, and not at all towards the base. It is therefore evident that in the course of time such a stem will approach nearer and nearer to a cylinder, and this accounts for the fact that the more trees are crowded in a wood the less tapering, that is the more cylindrical, are the stems.

As regards the formation of two rings in a growing season, it may be said that this will occur where any cause intervenes in the course of the growing season to put a temporary stop to the activity of the cambium. Later on, when the cause has been removed, the cambium will resume the formation of the wood ring, but the wood which it first forms after resumption is of the nature of spring wood, and consequently such later growth can be distinguished from that formed earlier in the season, and thus the whole year's growth partakes of the character of a double ring. If, for instance, after growth has begun the tree is completely defoliated by insects, as often occurs under a severe attack of the oak-leaf Roller Moth, the cambium is deprived of formative materials, and practically stops producing wood until the insect attack has passed and the tree has again reclothed itself with leaves. Interruption to growth will also occur where the new foliage is entirely destroyed by frost, as often happens in the case of certain trees—as, for instance, Walnut, Beech, etc.—about the end of May, and several weeks must elapse before the tree is again provided with a normal supply of foliage, and is therefore in a position to furnish the cambium with a sufficient quantity of nourishment.

The fact that when interruption of growth takes place the part of the ring formed after the interruption is, to begin with, of the character of spring wood, gives support to Hartig's theory that cells with large lumena and thin walls are directly associated with defective nutrition.

As has already been said, the presence or absence of vessels—which can in the great majority of cases be easily seen with the naked eye, and almost always with the aid of a pocket lens—at once enables one to determine whether one is dealing with a broad-leaved tree or with a conifer. Sometimes these vessels are much larger and more numerous in the spring wood than in the autumn wood, in which case it is usual to talk of ring pores—as, for instance, in the Oak, Elm, Ash, and Spanish Chestnut (Fig. 79). In other cases the vessels are neither markedly larger nor more numerous in the spring wood, *e.g.* Plum, Birch, Lime, Maple, Willow, Poplar (Fig. 83). In still other cases the vessels, although more numerous and larger in the spring wood, are not markedly so, instances of this state of things being furnished by the Beech and Walnut (Fig. 81).

Hard Woods and Soft Woods

Both popularly and scientifically there is a certain amount of confusion in the terms adopted to distinguish what are called conifers and broad-leaved trees. In popular language the two groups are frequently spoken of as soft woods and hard woods respectively, but many so-called hard woods, *e.g.* Poplar, Willow, Lime, really produce a much softer wood than the timber of some of the so-called soft woods, *e.g.* Pitch Pine, Yew, Larch. On the Continent it is not unusual to divide trees into two great classes, called respectively broad-leaved trees and needle-leaved trees, and on the whole such a distinction is fairly satisfactory; but since "needle-leaved" is intended to be synonymous with conifer, it is well to remember that some conifers, *e.g.* the Maidenhair tree, have leaves that are as much entitled to be called broad as typical leaves of the other class. In some countries trees are divided into resinous and non-resinous groups, and such a classification has a good deal to support it, although here, also, exceptions occur, some of the so-called resinous trees not being particularly distinguished by the production of this substance. Scientifically the broad basis of classification is the number of cotyledons, and botanists generally speak of conifers and dicotyledons, but all so-called dicotyledons have not necessarily two cotyledonary leaves, *e.g.* Sycamore seedlings sometimes show three and occasionally four such leaves, while many conifers have only two cotyledons, *e.g.* Librocedrus, Cupressus, Taxus, Thuja, Juniperus. But, as a rule, conifers have more than two cotyledons, *e.g.* Pinus, Larix, Picea, Abies, Cedrus, Tsuga, Pseudotsuga, which have generally six or eight, but some species may have as few as three or four, and others as many as ten or twelve.

Relationship of Ring Breadth to Quality

As is well known, the quality of wood has a fairly direct relationship to the breadth of the ring. Popularly it is supposed that narrow-ringed wood of all kinds is of higher quality than broad-ringed wood, or in other words, it is supposed that slow-grown timber is of higher quality than that which has grown fast. In point of fact, there is no general rule applicable to all timbers, because coniferous timber follows one rule and dicotyledonous timber another. Of course, something depends on what we mean by quality, which embraces such varying characters as durability, lustre, colour, figure, and others, but of these the most important is durability, and it is this which we shall particularly keep in mind in the present connexion. For all timbers it may be stated that the quality of timber is in fairly direct relationship with the proportion of each ring occupied by the autumn-wood zone—that is to say, the larger the proportion of dense wood the heavier and the stronger is the timber and the more resistant is it to decay. Whatever influences the relative proportion of autumn wood to spring wood must have considerable effect on the quality. Taking first of all the wood of conifers, it is found that the poor spring-wood zone may make up three-fourths or more of the whole ring breadth, or it may be as little as one-half, or even one-fourth (Fig. 36). When the cambium of a tree becomes active in the beginning of the growing season, it commences to form the so-called spring-wood zone, but in the case of a conifer this zone may be comparatively narrow or comparatively wide—that is to say, the time may be reached quite early when the wood that is formed partakes of the character of autumn wood. The results of experiment and observation go to show that when the rings of a conifer are very broad, the excess of breadth beyond the average is largely accounted for by extra breadth in the spring-wood zone, the autumn-wood zone remaining comparatively unaffected. This means then that, as a rule, broad-ringed coniferous wood is of poor quality, because it contains a relatively large proportion of spring wood and a relatively small proportion of autumn wood (Fig. 36). It has been found that a conifer that begins to grow early in the season forms a comparatively broad ring, and that the wood which is formed first in the season contributes for

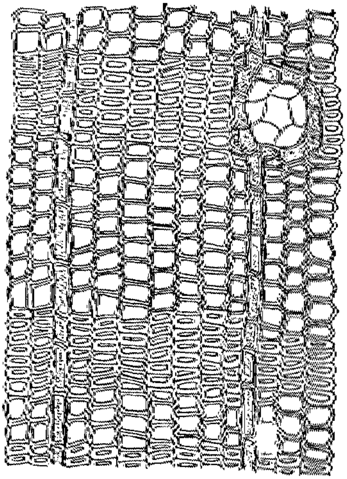

Fig. 36.—Diagrammatic T.S. of Pine, showing a ring with much spring wood and a ring with little spring wood.

the most part to this abnormal breadth. On the other hand, conifers that start growth late in the season very soon cease to produce spring wood, and proceed to produce the denser autumn wood, and under such circumstances the quality of the wood will, other things being equal, be high. The circumstances under which a conifer will begin to grow early in the season are, for instance, a southern latitude, a low elevation, and a southern exposure, and these are conditions which result in the production of coniferous wood with broad rings, and therefore of wood of low quality. The growing season begins earlier and is more prolonged in the south of England, for instance, than in the north of Scotland, and the difference is still greater if we compare the growing season in the British Isles with that in the north of Scandinavia or Russia. The theory of the subject is found to be consistent with practical experience, for it is known that the quality of the timber of conifers grown in the south of England is lower than that which is produced in the Highlands of Scotland; and, furthermore, Pine and Spruce timber imported from the north of the Baltic or from Archangel is of higher value and commands a higher price than similar timber grown in Central Europe. In the former case the rings will be narrower and the proportion of autumn wood to spring wood will be greater and the durability will be higher. Similarly as regards coniferous timber grown in this country at or near sea-level, as compared with timber of the same species produced at an altitude of, say, 1200 or 1500 feet. In the latter case the growing season starts later, and in a short time the conditions of growth attain their maximum, with the result that but little of the poor spring wood is produced, and the wood ring contains a relatively large quantity of autumn wood. It is also a matter of practical experience that timber taken from near the crown of a conifer is of poorer quality than that which is taken from near the ground, that is to say the top cuts are of lower quality than the bottom cuts. While other factors are, no doubt, at work in such a case, the period when the cambium begins to produce wood has considerable influence, for it is known that growth in the upper part of a tree may have proceeded for a week or two before the cambium near the ground has commenced to form new wood.

In the case of dicotyledonous trees the argument is reversed, for the reason that such timber contains in every ring vessels, an element that is entirely absent from the main body of the wood of conifers. As has already been pointed out, the vessels in a dicotyledonous tree are often larger and more numerous in the spring wood, in some cases markedly so, in other cases less so, and even where such grouping is not conspicuous it will always be found that vessels are at least not so abundant or so large in the autumn-wood portion of the ring. The argument may be best developed by confining attention to such wood as Oak, which has got a very well-marked pore zone (Fig. 37). If broad rings and narrow rings of Oak are examined it will be found that the breadth of the pore zone varies but little in the two cases, that is to say the absolute width of this zone in the wood ring is practically as great in a narrow ring as it is in a broad ring (Fig. 37). In the broad ring the extra width of the ring as a whole is accounted for by the formation of an increased amount of dense, firm, autumn wood, so that, whereas in a broad ring the proportion of porous spring wood to autumn wood may be as 1 to 3, in a narrow ring it may be as little as 1 to 1, or even less.

When dicotyledonous wood of rapid and slow growth is investigated as regards specific gravity, it is always found that broad rings give higher figures than narrow rings, that is to say the amount of wood substance in a given volume is higher in the case of a broad ring than in the case of a narrow ring, and as it is solid wood substance which gives strength and durability to wood, broad-ringed dicotyledonous timber must be of higher quality than narrow-ringed timber.

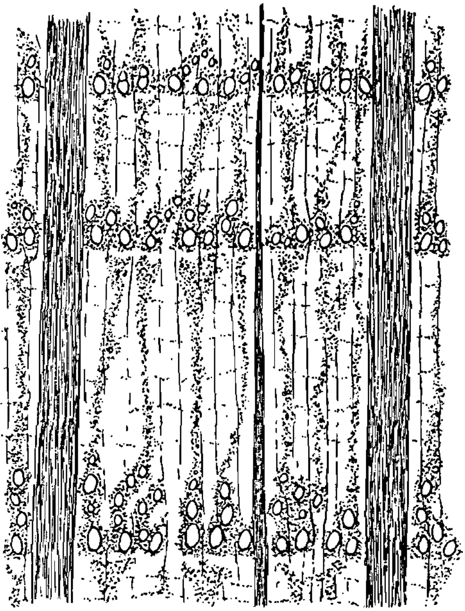

FIG. 37.—T.S. Oak. (Diagram.) A broad ring and a narrow ring. × 10.

Of course this statement only applies to the quality of durability, and it may be that purchasers are prepared to pay a higher price for narrow-ringed wood on account of the better figure or more attractive grain. The theoretical argument in the case of dicotyledonous timber is also consistent with practical experience, Oak, for instance, being considered of higher quality and more valuable when it is grown in the south of England as contrasted with Scotland, and when it is grown in a fertile valley rather than when grown at a high altitude. In Europe the best Oak is probably that which is produced in the Danubian area, where, of course, the growing season is much longer and the conditions of growth altogether more stimulating than in the British Isles ; and such Oak is characterized by relatively great breadth of ring.

The Specific Gravity of Wood

When the specific gravity of wood is ascertained, it is found that it decreases as the stem is followed upwards. It is also found that specific gravity decreases as a root is followed along the ground from the stem. In both cases the result is due to the same cause, namely, that the same volume of water has to pass any given point. Thus in the case of a stem, the water that reaches the lowest branches is the same in quantity as that which entered from the ground, so that the stem being of less diameter it means that the channel conveying the water is relatively greater in the upper part of the stem than near the ground. Thus Hartig found in the case of a Beech tree that the number of vessels per square millimetre of cross-section in the wood between the 120th and 150th rings was 115 at a height of 4 feet from the ground, whereas it was 210 at a height of 69 feet. This means, therefore, that the wood is more porous as one goes up the tree.

The specific gravity also is higher in the case of small-sized conifers of the same age taken from the same wood. This, again, depends on the breadth of the ring, which, of course, is less in the trees which are of the same age though of smaller size. He found, for instance, in the case of a tree falling into Class 1, that is to say the largest size, that the specific gravity of the whole stem was ·38 ; whereas in the case of Class 6, the smallest size, it was ·55.

Schwappach also has investigated Scots Pine. He found that there is a definite relationship between specific gravity and the percentage of autumn wood and the average breadth of the ring. His figures bearing on this point are summarized herewith, and the table shows that at the height of 26 feet the specific gravity is lower than at 3 feet. With an average ring breadth of 6·6 millimetres and a percentage of autumn wood of 37·3 the specific gravity is ·511 ; while with an average ring breadth of 2·9 millimetres and a percentage of autumn wood of 49·1 the specific gravity is ·560.

RELATIONSHIP BETWEEN BREADTH OF RING, SPECIFIC GRAVITY AND PERCENTAGE OF AUTUMN WOOD IN A SCOTS PINE. (SCHWAPPACH.)

Height.	Between the years.	Av. breadth of ring. mm.	Per cent. Autumn wood.	Sp. gr.
3 ft. - -	0-30	6·6	37·3	·511
	31-60	3·8	47·7	·530
	61-90	2·9	49·1	·560
26 ft. - -	0-30	9·3	23·7	·434
	31-60	3·8	32·5	·477
	61-90	2·3	31·2	·477

Timber Strength

When the wood was subjected to the test of crushing, Schwappach found that, on the average of 64 Scots Pines of varying age and height, in the case of trees whose age is between 60 and 120 years, at 4 feet from the ground the force required to crush a section was 7154 pounds per square inch of cross-section, at 30 feet it was 6256 lbs., and at 52 feet it was 5418 lbs. This shows that the relationship between specific gravity and resistance to crushing is a fairly definite one. Just as the specific gravity of a tree decreases as you proceed upwards from the ground, so does the resistance to crushing similarly diminish.

AVERAGE RESISTANCE TO CRUSHING IN LB. PER SQ. INCH OF 64 SCOTS PINES OF VARYING AGE AND HEIGHT. (SCHWAPPACH.)

	At 4 ft.	At 30 ft.	At 52 ft.
Trees 61-120 years -	7154	6356	5418
Trees over 120 years -	7031	7024	6256

On the average for 10 stems it was found :

When percent. of Autumn wood under 30, resistance = 5792
,, ,, ,, was 31-35, ,, = 6469
,, ,, ,, ,, 36-40, ,, = 7295
,, ,, ,, over 40 ,, = 7959

Eccentric Growth

There is a peculiarity in the growth of trees that must be mentioned, namely, eccentric growth, where the pith is not in the mathematical centre of the section, but stands to one side of it. In other words, the radii are of unequal length. Eccentric growth is met with in all trees, but is most consistent in conifers, and it is to this group that the following notes are confined.

If a branch of a conifer be examined it will be found that the greatest diameter is on the lower side, a condition of things called hyponasty (Fig. 38). Branches are generally more or less horizontal in position, so that the force of gravity tends to bear them down towards the ground. Under these circumstances the cambium on the upper side of a branch is in a state of distention, while that on the under side is being compressed, and this compression along the line of the cambium seems to result in much greater growth. Moreover, the character of the wood is distinctly different from normal timber, the cells showing great secondary thickening. This thickening of

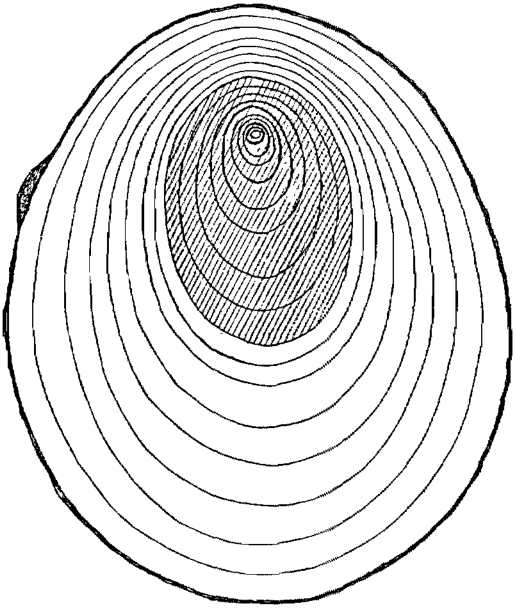

Fig. 38.—Ex-centric growth of a Scots Pine branch. (Semi-diagram from actual specimen.)

the internal wall of the cells is extremely hard, and that is the reason why knots and branches of the stem, for instance, are much harder than the wood of the stem. This timber, in fact,

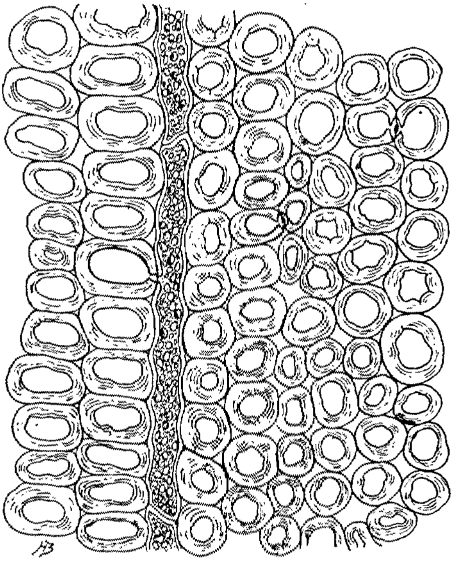

FIG. 39.—"Rotholz" of *Picea excelsa*. T.S. (treated with strong H_2SO_4). (× about 400.)

is quite glassy in structure, as is realized by those who are in the habit of lopping conifers (Fig. 39).

If a shoot of a conifer is taken and bent over, being kept in that position during summer, it will be found that much more growth is formed on the concave than on the convex side of the shoot. Here, again, the convex side is under distention and the concave side under compression, as in the case of a branch (Fig. 40). In the case of conifers growing on a steep hillside it will be found that the pith is always at a greater distance from the side of the tree next the hill than on the other. Now this can be explained by the condition of things which prevails, namely, the tree is affected by wind more on the side towards the valley, that is to say there is a tendency for the tree being blown towards the hill. In other words, the tree is in much the same position as a branch, the concave side being towards the hill and the convex side on the opposite side, with the result that greater growth is made on the side towards the hill than on the other side. Again, supposing a tree is blown over entirely or partially, but so that it continues to grow in an inclined position, it will be found that the growth formed after it has attained this position is eccentric, the greater diameter being on the under side of the stem, that is to say the under side of the stem is subjected to pressure along the line of the cambium, whereas on the upper side it is distended.

A conifer completely isolated also shows eccentric growth, in this country the greater radius being towards the north-east side, for the simple reason that the prevailing winds come from the south-west and the tree is therefore blown towards the north-east, with the same result as before, namely, that the greater growth is on the side towards which the tree bends. Trees grown along the margin of a wood show greater growth towards the field side, because such trees have more branches on that side and consequently incline to bend over towards the field. Roots also show

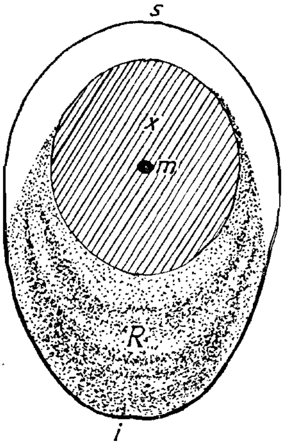

FIG. 40.—Stem that has been bent over.

m = pith; x = wood formed before bending of branch; R = "rotholz" (pressure wood, "bois rouge") on the lower side "i" of stem.

eccentric growth, and if the roots of a Spruce be examined, which are generally more or less horizontal, it will be found that the greater growth is on the upper side, because here also as the tree is swayed by the wind the compression is on the upper side, and the distention on the under side.

It has been said that in the case of conifers this is quite consistent, whereas in the case of dicotyledonous trees there is no such consistency. A great deal of work has been done in recent years on the inconsistency of the growth of dicotyledonous trees, but it would take us too far to attempt to digest the results of the various experiments. Suffice it to say that the wood (hemicellulose) formed by dicotyledons is very much softer than the wood of conifers, and consequently if support is to be given to a horizontal branch in the case of a conifer the greater growth is on the under side, whereas in the case of a dicotyledon the greater growth will usually be found on the upper side. Supposing that one is called upon to strengthen a projecting beam, and that one has two kinds of material with which to strengthen it, namely, cast iron and leather, one would support the beam best by placing the cast iron below and the leather above. An analogous condition of things is found in the growth of trees, the hard stuff in the case of a conifer being deposited underneath, and the soft stuff in the case of a dicotyledon being deposited above. The eccentricity of growth may be very marked, the radius on one side being no more than one inch, whereas on the other side it may be as much as a foot.

Duramen

After the year of formation no change takes place in the annual ring, except in the case of those trees which form heart wood or, as it is better called, duramen. As is well known, certain trees are characterized by a markedly distinct centre, the heart wood or duramen, which is more or less sharply marked off from the outer wood, the so-called sap wood or alburnum. The duramen may be conspicuously distinct in colour, as, for instance, in the Yew, Laburnum, *Robinia*, Elm, Larch, etc., or it may be less clearly distinguished, as in the Scots Pine, Ash, etc. (Fig. 41). Then, again, the duramen may embrace the whole of the centre of the tree to within an inch, or less, of the outside, e.g. *Robinia*, Yew, Spanish Chestnut, etc., or it may be enveloped in a zone of alburnum three or four inches wide, *e.g.* the younger classes of Scots Pine, Ash, Elm, etc. In the case of certain species the formation of duramen begins when the tree is only a few inches in diameter (Spanish Chestnut); whereas in the case of others its formation is delayed until the tree is a foot or

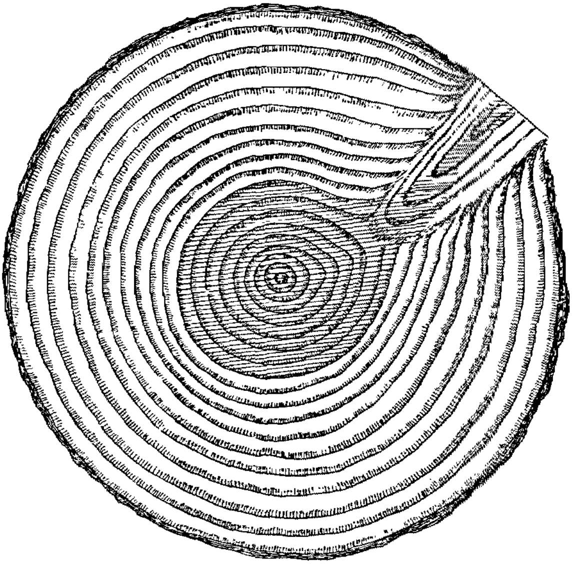

FIG. 41.—Trans. Sect. of Douglas Fir, to show Duramen. (From specimen.)

more in thickness (Scots Pine). Certain trees never form true duramen at all, *e.g.* Beech, Lime, Spruce, Silver Fir, etc., and in their case a darker-coloured centre is not duramen, but is the result of incipient decay.

When wood passes into the condition of duramen it undergoes fairly well-defined changes. A certain amount of solid matter, of the nature of gum, resin, etc., is deposited between the micellae, that is to say it impregnates the cell-walls, displacing water of imbibition in the process, and the result is that when such wood is subjected to desiccation it shrinks less than would otherwise be the case, because there is not the same opportunity for the micellae to come

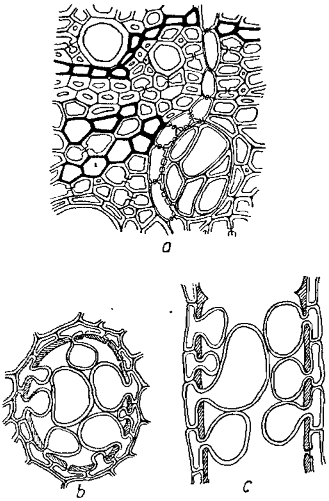

Fig. 42.—Diagrams showing how the process of Tylosis takes place. (All after Jeffrey.)

a, T.S. Heart-wood in Oak with Tyloses in large vessel. *b*, trans. sect. *c*, long. sect.

close together. Duramen, therefore, shrinks less than alburnum, and in this respect its technical properties are improved. The solid substance that is deposited in the duramen is the result of the oxidation of gummy and resinous substances present in the wood, and such oxidation is usually associated with a darkening in the colour. Then, again, that peculiar cellular growth that is known as tylosis is usually a marked accompaniment, in the case of dicotyledonous trees, of the formation of duramen (Fig. 42). The living cells in the neighbourhood of the vessels are in some way stimulated to active division, pushing processes through the pits of the vessels and thus invading the internal cavity, where they continue actively to divide and grow, and often completely plug up the lumen with thin-walled cellular tissue, the so-called tylosis. As a result of the deposition of the solid material in the cell walls themselves and of the formation of tylosis in the lumena of the vessels, duramen is much poorer both in air and in water than alburnum, and these are amongst the main causes of the increased durability that is associated with this kind of wood. Then, again, duramen holds little if any starch, this substance having been converted into tannic derivatives which have been deposited in the cell-walls. The absence of starch is also a cause of the improved durability of duramen, because starch is an important fungus food, and its absence, therefore, creates conditions unfavourable to the life of wood-destroying organisms.

Timber Investigation

Wood has certain physical properties which may now be examined a little in detail. Suppose we take a piece of Silver Fir wood and proceed to investigate it so as to determine its specific gravity and other properties. Assuming that a piece of Silver Fir weighs when fresh 87·60 grammes, and that when it has been thoroughly dried it weighs 34·83 grammes, we can determine its volume by immersing it in a xylometer. Its volume when fresh is found to be 90 cc., and when dry amounts to 78·84 cc. By means of these data we can now proceed to make the following determinations :

1. The specific gravity of any substance is its weight compared with the weight of an equal volume of water. Therefore the specific gravity of wood in a fresh condition is decided by taking the fresh weight and dividing it by the fresh volume, which in this case works out at ·973. By the metric system we know that a

cubic centimetre of water weighs one gramme, so that the volumes are essentially the weights.

2. The specific gravity of the dry wood is similarly proved by taking the dry weight and dividing it by the dry volume. In this case the result was ·442.

3. To find what the percentage of shrinkage is, that is to say the volume lost in passing from the fresh condition to the condition of being dry, we deduct the dry volume from the fresh volume and divide by the fresh volume, and multiply the whole by 100, which gives us 12·4.

4. Next, we may determine the weight of organic substance plus ash in the fresh weight. This will be found by dividing the dry weight by the fresh weight and multiplying by 100, and the answer in this case is 39·76.

5. We may also determine the percentage of water in the fresh volume. This is found by deducting the dry weight from the fresh weight and dividing by the fresh volume and multiplying by 100, and in this piece of wood we are investigating the answer is 58·63.

6. The percentage by weight of water in the fresh weight is found by deducting the dry weight from the fresh weight and dividing by the fresh weight and multiplying by 100, and the answer is 60·24.

7. Next we can determine the volume of the cell-walls in the fresh volume, which is found by dividing the dry weight by 1·56, the answer being 22·33, so that the percentage is 24·81.

Although we know that wood varies in weight, it has been found by investigation that when the water and air are withdrawn from wood the specific gravity is invariably 1·56. This means that the lightest wood of all will sink like a stone in water if the air has been withdrawn from it. If a piece of wood is placed in water and left in a sufficient time it becomes what is called water-logged, that is to say the water expels all the air from the cells and the wood sinks to the bottom.

8. The percentage volume of air in the fresh volume can be determined by deducting the volume of cell-walls plus water from the fresh volume. In this case the answer is 16·56 per cent.

9. The next thing to do is to find the volume of the cell-walls when saturated with water. This is determined by taking the dry volume of the cell-walls, to which is added the volume of imbibed water, because it is only imbibed water that makes any difference to the volume. In the case of Silver Fir it is found to be 50 per cent., so we take 22·33 and add 50 per cent. to it, namely, 11·16 cc., and this comes to 37·21 per cent.

10. The volume of liquid water in the lumen will be found by taking the fresh volume and deducting from it the volume of the saturated cell walls plus air, and the answer is 46·23 per cent.

11. Lastly, we can determine the percentage volume of imbibed water by taking the percentage volume of water in the fresh volume and deducting from it the percentage of volume water in the lumena, and the answer is 12·40.

These calculations are summarized below.

$$\textit{Abies}\begin{cases}\text{Weight of fresh wood} = 87{\cdot}60\text{ g.}\\ \quad\text{,,}\quad\text{dry}\quad\text{,,}\quad = 34{\cdot}83\text{ g.}\\ \text{Volume fresh}\quad\text{,,}\quad = 90\text{ cc.}\\ \quad\text{,,}\quad\text{dry}\quad\text{,,}\quad = 78{\cdot}84\text{ cc.}\end{cases}$$

1. Sp. gr. of fresh wood $= \dfrac{\text{fresh wt.}}{\text{fresh vol.}} = \dfrac{87{\cdot}60}{90} = {\cdot}973.$

2. „ dry „ $= \dfrac{\text{dry wt.}}{\text{dry vol.}} = \dfrac{34{\cdot}83}{78{\cdot}84} = {\cdot}442.$

3. Percentage shrinkage

$$= \frac{(\text{fresh vol.} - \text{dry vol.})\ 100}{\text{fresh vol.}} = \frac{(90 - 78{\cdot}84)\ 100}{90} = 12{\cdot}4.$$

4. Percentage wt. org. substance (+ ash) in fresh wt.

$$= \frac{\text{dry wt. } 100}{\text{fresh wt.}} = \frac{34{\cdot}83 \times 100}{87{\cdot}60} = 39{\cdot}76.$$

5. Percentage vol. of water in fresh vol.

$$= \frac{(\text{fresh wt.} - \text{dry wt.})\ 100}{\text{fresh vol.}} = \frac{52{\cdot}77 \times 100}{90} = 58{\cdot}63.$$

6. Percentage wt. of water in fresh wt.

$$= \frac{(\text{fresh wt.} - \text{dry wt.})\ 100}{\text{fresh wt.}} = \frac{52{\cdot}77 \times 100}{87{\cdot}6} = 60{\cdot}24.$$

7. Vol. of dry cell-walls in fresh vol. $= \frac{\text{dry wt.}}{1{\cdot}56} = 22{\cdot}33$ cc.

$\therefore$ percentage $= \frac{22{\cdot}33 \times 100}{90} = 24{\cdot}81.$

8. Vol. of air in fresh vol.
$=$ fresh vol. $-$ (vol. of cell-walls $+ H_2O$)
$= 90 - (22{\cdot}33 + 52{\cdot}77) = 90 - 75{\cdot}10 = 14{\cdot}90 = 16{\cdot}56\ \%$

9. Vol. of cell-walls when saturated with water
$=$ dry vol. of cell-walls $+$ vol. imbibed H_2O
$= 22{\cdot}33 + 11{\cdot}16$ (found to be 50 per cent. for Abies)
$= 33{\cdot}49$ cc. $= 37{\cdot}21$ per cent.

10. Vol. of liquid water in lumina
$=$ fresh vol. $-$ (vol. of saturated cell-walls $+$ air)
$= 90 - (33{\cdot}49 + 14{\cdot}90) = 90 - 48{\cdot}39 = 41{\cdot}61$ c.c.
$= 46{\cdot}23$ per cent.

11. Percentage vol. of imbibed water
$=$ percentage vol. H_2O in fresh vol.
$-$ percentage vol. H_2O in lumina $= 58{\cdot}63 - 46{\cdot}23$
$= 12{\cdot}40.$

Percentage vol. of imbibed water (11) = 12·40
" " liquid " (10) = 46·23
" " air " (8) = 16·56
" " cell-walls (7) = 24·81
100·00

Percentage wt. of water (5) = 60·24
" " org. sub. (4) = 39·76
100·00

Medullary Rays

An invariable constituent of wood is the medullary rays, which on a cross-section can often be easily seen with the naked eye, running in straight lines from the centre, or some other part of the stem, out to the cortex. A few of the medullary rays, the so-called primary rays, actually start in the pith or medulla and are, therefore, continuous from the very centre right out to the bark (Fig. 30). Most of the medullary rays, however, originate at some point between the pith and the bark, but wherever they originate they are at least continuous as far as the cortical covering of the tree. A medullary ray sometimes consists entirely of parenchymatous cells, and in none are such cells entirely absent. It

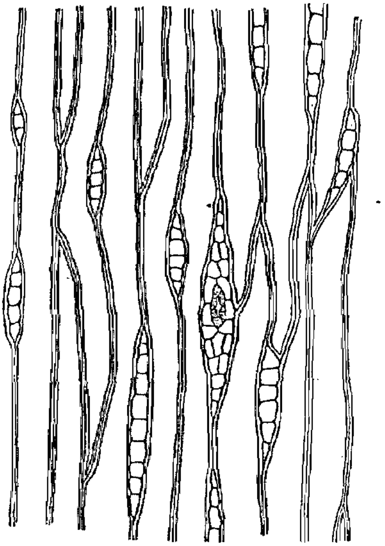

FIG. 43.—Tan. Sect. of *Pinus silvestris*. × 400.

may be only a single cell wide (uniseriate), and this is the case with most of the medullary rays of conifers (Fig. 43), or it may have a breadth of several cells (multiseriate), as, for example, in many of the rays of the Beech, Oak, and other broad-leaved trees, as well as in the rays of conifers which possess horizontal resin ducts,

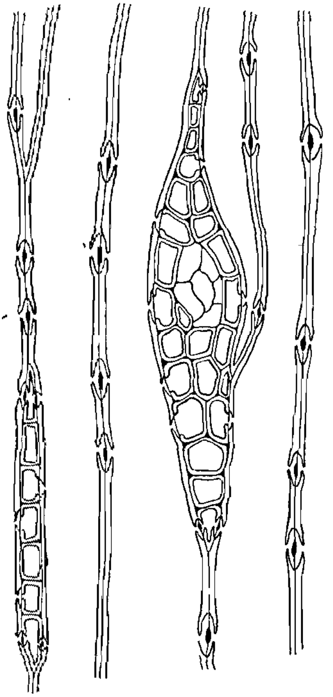

FIG. 44.—Tan. Sect. of Douglas Fir. × 400.

e.g. Pines, Larch, and Douglas Fir (Fig. 44). As regards depth, this varies a good deal according to the species of the tree, but in conifers the medullary rays are usually very shallow, having a depth of perhaps five or six cells, although often only two or three cells, sometimes, however, a dozen or more (Fig. 109). In the case, however, of dicotyledonous trees the depth is often much greater, and the broad rays of, for instance, the Oak may have a depth of more than an inch. One can, of course, ascertain approximately the depth of a medullary ray by examining it either on a radial section, when one has a view of its side, or on a tangential section, where its end is presented to view (Figs. 99 and 100). It is the medullary rays that give the so-called silver grain to the radial section of wood. As above

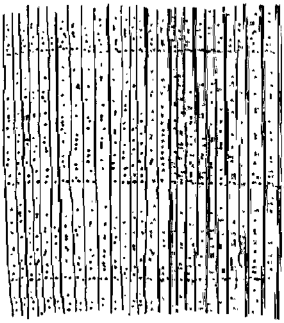

FIG. 45.—Lime. × 10.

mentioned, in conifers most of the medullary rays have *a breadth of only a single layer of cells*, except where a resin duct occupies a medullary ray, in which case it widens out in the middle to provide accommodation for the duct, and such rays immediately above and below the duct may

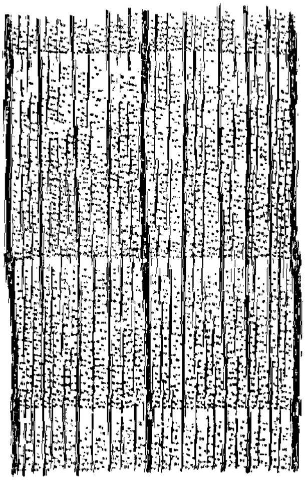

FIG. 46.—T.S. Beech. × 10.

be two or three cells wide (*fusiform rays*). Where a tree possesses resin ducts many of these are situated in the medullary rays, and these communicate with the ducts which run longitudinally in the stem, so that if a piece of bark be removed from such a tree the ends of the radial ducts are ruptured and the resin flows to the surface of the wound. As resin exudes on the surface further supplies move down the longitudinal ducts and are diverted into the radial ducts, so that the bleeding of the tree may continue for a long time, the supplies being brought forward from points at considerable distance from the exposed surface.

In the case of conifers, as has been said, medullary rays are invariably very fine, and can hardly be made out with the naked eye, although visible enough on a smooth transverse section with the aid of a pocket lens. In dicotyledonous trees the medullary rays may also be so fine as to be unrecognizable with the unaided eye, as, for example, in the Pear, Apple (Fig. 90), Birch (Fig. 91), Horse Chestnut (Fig. 92), Willow (Fig. 93), and Poplar. In other hardwood trees the rays though fine are a little broader, as, for example, in the Ash (Fig. 73), Hickory, *Robinia* (Fig. 77), Spanish Chestnut (Fig. 79), and Walnut (Fig. 81). In another group of trees, which comprises the Elm (Fig. 75), Plum, Cherry (Fig. 80), Maple (Fig. 87), and Lime (Fig. 88), the rays can be made out with comparative ease by the unaided eye; while in the true Plane tree (*Platanus*, Fig. 82) all the medullary rays are comparatively broad and conspicuous. In some trees, however, the medullary rays vary considerably in breadth, some being very broad and occupying a considerable portion of the whole transverse section, while others are so fine as to be scarcely recognizable. This group of trees includes the Oak (Fig. 78), Beech (Fig. 83), Hornbeam (Fig. 84), and Alder (Fig. 86).

Storehouse of Reserve Material

Where the medullary rays run in the alburnum they constitute an important storehouse of starch and other reserves of plant food. They are excellently adapted for this purpose, because every medullary ray is in communication with the cambium, so that when the latter is active and in need of supplies of material from which to form new tissues, it has the power of attracting the reserves of food and thus of being able to utilize them. If the medullary rays of a tree be examined with the microscope in winter or spring it will be found that the cells are for the most part filled with starch, but when increase in thickness of the stem begins in early summer the starch is withdrawn to a greater or less extent from the rays, and, in the first instance, from the part of the rays which lies in the last wood ring. As the season advances the requirements of the cambium attract starch from deeper rings, so that the store cells may be partially or completely emptied to the depth of five or six wood rings. Later in the season, when the annual growth has been completed, the tree proceeds to replenish the depleted portions of the rays, which when autumn is well advanced will again be completely filled and be in position to furnish formative material to the cambium when it again becomes active in the following summer.

The Production of Seed in Relationship to Reserve Material

Much more complete depletion of the stock of reserve materials in the medullary rays occurs during a seed year. The production of seed makes great demands upon the reserve of plant food, and in such years the exhaustion of the supplies will be much more complete and will extend deeper than in the case of a year when little if any seed is being produced. Some trees bear seed at comparatively long intervals, and amongst common trees this is notably the case in the Beech, which produces a full crop of mast only once in eight or ten years. A good deal, however, depends upon the quality of the soil and other conditions of growth. If these are favourable the storehouses that have been emptied are more rapidly filled, with the result that full crops of seed are borne more frequently than under other circumstances. Although the Beech is about the best example of a tree showing marked periodicity of seed-bearing, one also finds this character in the case of the Oak, which bears a full crop of acorns perhaps once in four or five years. But the same sort of thing is met with in all trees, none producing a full crop every year, but only after two or three years' interval. The crop of seed in any particular year is not so much influenced by the character of that season, except as regards maturing and ripening, as by the character of the preceding season. If this has been specially warm and genial the tree has had the opportunity of elaborating an unusually large amount of plant food, with the result that in the following year it may be in a position to bear a full crop of seed.

The fact that the production of seed reduces the reserve material in the stem was investigated by Professor Weber of Munich, and a summary of his results is given in the accompanying table. From this it will be seen that the total percentage of ash is not affected by seeding, but that the nitrogen is greatly reduced by the tree bearing seed. Of the individual ash constituents it was found that lime was least affected by the production of seed, and that the percentage of magnesia was most affected. As was to be expected, the outer rings were more drawn upon than the central rings of the wood. Thus in the case of magnesia the reduction was from 29·2 to 12·6 in the case of the 30 outer rings, whereas there was only a reduction of 15 to 13·4 in the case of the 60 central rings.

TWO 150-YEAR-OLD BEECHES. (WEBER.)
A = 2 years before seeding.
B = year after seeding.

	Total percentage.		Ash Constituents in percentage of Total.				
	Ash	N	K_2O	CaO	MgO	P_2O_5	SO_3
Bark *A*	5·7	—	4·6	82·0	3·6	1·0	1·0
B	5·7	—	4·0	85·0	2·6	1·1	0·9
30 outer rings *A*	0·3	·25	24·5	27·7	29·2	8·4	6·7
B	0·3	·06	38·8	33·9	12·6	5·6	5·3
60 centre rings *A*	0·4	·15	41·5	29·4	15·0	2·3	3·2
B	0·4	·04	39·8	33·2	13·4	4·8	4·6

Not only are the storehouses of plant food in the medullary rays very completely exhausted by the production of seed, but they are also emptied completely, or for the most part, by defoliation produced naturally by insects, or, artificially, by hand-picking. The necessity to produce a fresh crop of leaves in the course of the growing season reacts upon the storehouses of plant food, which are compelled to yield up their supplies, and it is at their expense that such a tree is enabled to re-clothe itself with foliage.

It may not be generally known that if a tree is felled in spring and lopped of its branches and left lying in a shady place the cambium will become active in summer and will form a certain amount of wood. Such a ring formed under these circumstances is produced at the expense of the reserve materials present in the medullary rays and other storehouses of the tree. Then, again, it has been noticed that when a tree has been cut down the stool will sometimes form quite a distinct callus along the edge of the section, and here again the new tissues are created at the expense of reserve materials, although if the stool is in the neighbourhood of other trees of the same species that had been left to grow it is possible that there may be a certain transference of materials from the living trees to the roots of the tree that had been felled. This is made possible by the fact that the roots of adjoining trees are often grown together where they abut on each other, and the few opportunities that present themselves of studying this subject go to show that such inarching is much more common than had been supposed.

Protective Tissues

In its earliest stages a young tree or young shoot is protected by a single layer of specialized cells with walls of corky substance called the epidermis (Fig. 47). The outer wall of each of the cells of the epidermis is much thicker than the others, such thickened portion being known as the cuticle. The function of the epidermis and cuticle is to protect the young tree or shoot against injuries, to keep out the spores of fungi, and to prevent the loss of water. Sometimes the

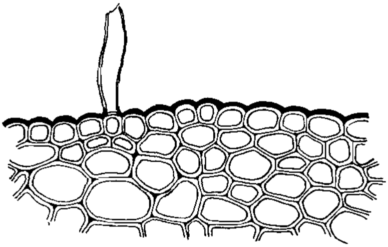

Fig. 47.—Cuticle and Epidermis of Willow. T.S. of a very young stem of Willow stained with Scharlach Red to show cuticle.

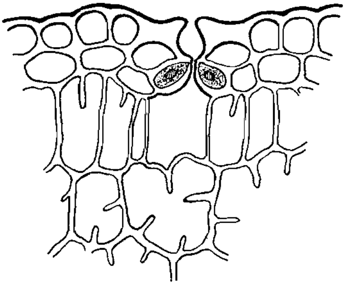

Fig. 48.—Stoma of Pine-leaf.

cuticle and epidermis receive additional support in their protective functions by a deposition of wax or resin, which gives a bluish or glaucous appearance to the surface, and is known as bloom. Such waxy covering is present on the shoots of several Willows (e.g. *Salix daphnoïdes*), on the Snake Bark Maple, and other trees. The epidermal layer not only envelops the young shoots, but also covers the upper and lower surface of leaves, where it is interrupted at frequent intervals; and especially on the lower surface, by apertures known as stomata (Fig. 48). It is by means of these stomata that air, including carbon dioxide gas, enters the tissues and circulates in the intercellular spaces. It is also through their agency that the tree expires water, as also oxygen that is liberated during the disintegration of the molecules of carbon dioxide gas.

Root Hairs

The epidermal cells frequently show lateral outgrowths, the most important of which are the root hairs which occur on the roots near the apex, and by means of which all the water and mineral food, including nitrogen, is absorbed (Figs. 49 and 50). The root hairs are closely in contact with the soil particles and with the water-film which surrounds them. This soil water is, of course, a weak solution of plant food, and it has the power of transfusing through the coat of the root hairs, the water being attracted by the stronger solutions of cell sap present in the internal cavity of the root hairs. Absorption of soluble plant food in this way can only go on so long as the solution in the soil is a great deal weaker than the solution inside the root hairs. Should the soil solutions become highly concentrated the plant is no longer able to feed, and death may rapidly occur.

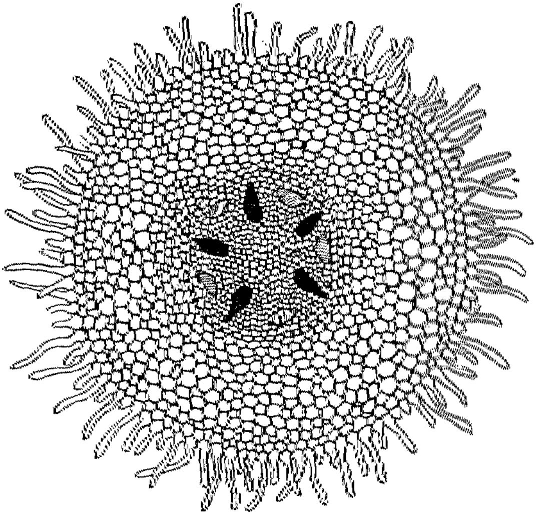

FIG. 49.—Semi-diagrammatic transverse section of a young Bean-root, to show Root-hairs. Xylem and Phloem bundles shown purely diagrammatically. × 40. (*From actual section.*)

Such injurious concentration practically never occurs in connection with tree growth, but it may occur as the result of agricultural or horticultural operations, as, for instance, where a farmer or gardener has applied large quantities

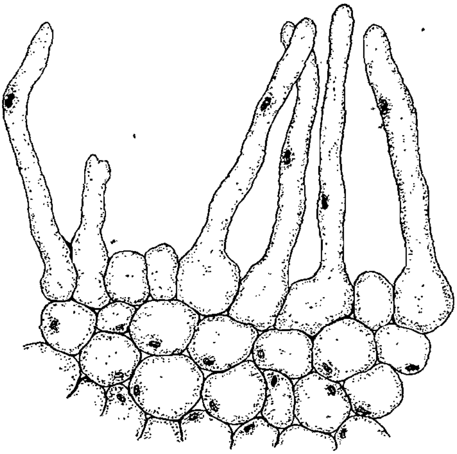

Fig. 50.—Root-hairs from a young Bean-root. (Actual specimen.)

of soluble manure like nitrate of soda or superphosphate of lime, excessive doses of which will do more harm than good.

Periderm

Very soon the simple epidermis and cuticle fail to give sufficient protection to the shoot, and at a very early stage the so-called periderm or corky layer is formed, which may be produced by division of the epidermal cells (Fig. 51) or by division of a zone of cortical cells below the epidermis. This dividing layer is known as cork cambium or phellogen (Fig. 53), and just as ordinary cambium produces bark on one side and wood on the other, so the phellogen forms cork on the outside and phelloderm on the inner side. Sometimes thin and thick layers of cork are formed each year, and when this is the case the periderm may be easily removed by peeling, and, in fact, often peels off naturally, as, for instance, in the case of the Birch and Cherry. Sometimes the cork is formed very irregularly and stands out in bold longitudinal ridges, as, for instance, in the Cork Bark Elm (Fig. 52), while in the case of the Cork Oak the production of cork is so abundant as to amount to a thickness of many inches; in fact, this tree produces the valuable material

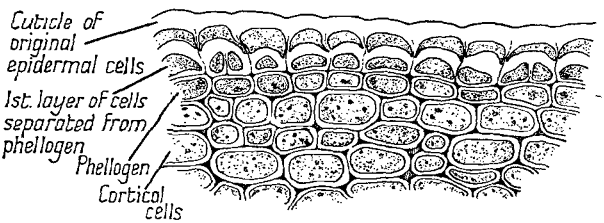
Cuticle of original epidermal cells
1st. layer of cells separated from phellogen
Phellogen
Cortical cells

Fig. 51.—Epidermis, with thick Cuticle, of Willow. A first-year shoot showing the beginning of cork-formation. (Camera-lucida drawing.)

which is stripped from the stems periodically and marketed as the cork of commerce.

Certain trees, as, for instance, the Beech and Hornbeam, never even in advanced life form any other protective covering than periderm. The cortical covering of such trees remains smooth till the end. In other cases the stems form nothing but periderm until comparatively late in life, as, for instance, the Aspen, Silver Poplar, and Silver Fir, and it is only the base of such trees that is rough and scaly. But with most trees the periderm alone soon proves insufficient to give complete protection, and in their case the

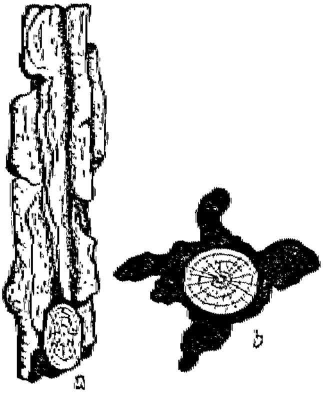

FIG. 52.—*a*, a portion of a shoot of cork-bark Elm, showing the irregular projections of the bark.

b, T.S. *of a similar shoot showing* the irregular projection of the bark.

stem is early covered with the material which botanists call bark. In popular language bark means everything outside the wood, but in the strict botanical sense bark is the dead excised cortex which generally adheres in the form of thick bark scales. The death of these tissues is due to the formation of periderm layers throughout the cortex, and when such layers are formed the transmission of water from the inside of the tree to the tissues situated outside of the periderm layers is prevented, with the result that the cortex so cut off dies, but generally remains adherent in the form of large scales or

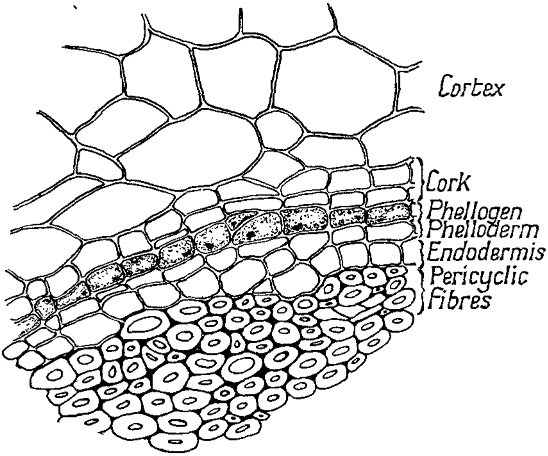

FIG. 53.—From × sect. of *Ribes* Stem.

plates of true bark. The accumulation of dead bark on old stems may reach a thickness of many inches, as, for instance, in the Wellingtonia, Californian Red Wood, etc., and even Scots Pine may carry bark three or four inches thick on the lower portion of old stems. In some trees, however, notably *Platanus*, the bark scales are periodically shed, this process usually occurring during winter.

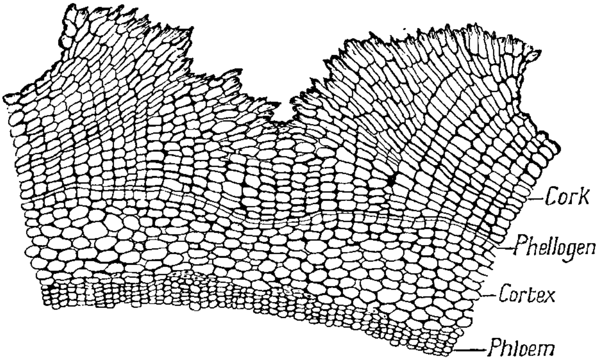

FIG. 54.—Elder, a lenticel.

As is well known, the cork or periderm offers almost complete resistance to the passage of liquids, and even air passes with difficulty. Directly the periderm is formed, diffusion of air into the shoots or stem would cease, were it not for the fact that most trees provide special passages which are known as lenticels (Fig. 54). These lenticels have often their origin in a stoma, and the lenticellular aperture communicates with a mass of loose tissue immediately below, known as spongy cork, which is formed by a definite phellogen layer. Lenticels are very prominent features of the surface of many shoots, *e.g.* Elder, Oak, Ash, etc.

As has been said, the cambium forms wood on one side and cortical tissues on the other side, and these cortical tissues include phloem or bast, which comprises elements corresponding to some extent to the elements of the wood. Thus the libriform fibres of the wood may be compared to the bast fibres of the phloem. The vessels and tracheids of the wood are comparable to the sieve tubes of the phloem; while the wood parenchyma is comparable to the bast parenchyma. The bast fibres are very tough, and may form a valuable article of commerce. Thus the Lime tree furnishes bast fibres, which in Russia are woven into a kind of coarse cloth extensively used for packing purposes; while Hemp, Jute, and Flax yield bast fibres which are of immense commercial value. It is the sieve tubes which are chiefly concerned with the conveyance of nitrogenous substances down the tree from the leaves; while the bast parenchyma is chiefly concerned with the downward conveyance of carbohydrates.

Healing of Wounds

When a branch is cut from a tree, or when the bark is stripped off, a wound is created which in the course of time heals up. Wounds are necessarily left in the process of pruning, and they heal by means of a callus tissue that forms along the line of the cambium and gradually spreads over the surface. In removing the branch of a tree by pruning one ought to be careful to cut as close to the stem as possible, because if one leaves a stump, the base of the stump will die and the healing of the surface cannot possibly take place. When a tree is wounded in any way the surface exposed should be protected by means of a waterproof covering, such as creosote or coal-tar. Coal-tar makes an excellent healing cover, because not only does it exclude air and water, but it is also elastic to some extent and responds to the swelling and contraction of the surface. The callus tissue is formed along the edge of a wound by reserve material which is stored up in the tree, or by means of the material sent down directly from the crown. It follows, therefore, that a wound in the upper part of the tree heals quicker than one near the bottom. It also means that too many wounds should not be made in the tree at one time, or there will not be enough plastic material to cause rapid healing.

Leaves

Leaves are usually more or less flattened members, although in the case of many conifers they may be needle-shaped, and their principal function is to expose a large surface to the sun's rays, so that the decomposition of carbon dioxide gas and the manufacture of starch may be facilitated (photosynthesis). Except in the case of special varieties, the leaves of trees are always green, and, as is well known, the green colouring

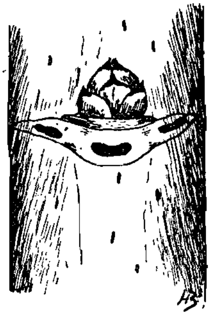

FIG. 55.—The leaf-scars of sycamoro are very variable in shape, and while the bundle-scars tend to show an arrangement in three groups, the groups, particularly the two lateral ones, are very frequently distinctly *compound*; and five distinct bundle-scars per leaf-scar may be frequently seen in the specimens examined. (× about 3½.)

matter (chlorophyll) is instrumental in the disruption of the carbon dioxide gas molecule and in the fixation of carbon. The leaves are attached to the stem by means of a stalk or petiole, which contains fibro-vascular bundles through which water and nutriment circulate between the leaf and the stem. When the leaf drops off it leaves a mark or scar upon the shoot or stem, and this scar bears the marks of the ruptured ends of the fibro-vascular bundles, the number of which can assist us to identify shoots of deciduous trees during winter, when the foliage is not present to guide us. Thus in the case of Willows, Poplars,

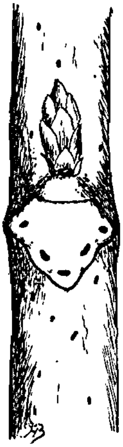

FIG. 56.—Leaf-scar of Horse-Chestnut. (From actual specimen.)

Birch, Elm, *Acer*, and several other trees, each scar is marked with three fibro-vascular bundles (Fig. 55); while in the case of the Hazel, *Sorbus*, and some other trees, the number of marks is five. These marks are very conspicuous on the scar left by the fall of the leaf of the Horse Chestnut, the actual number depending on the number of leaflets of which any particular leaf of this tree may consist, being very often seven, but may be as low as three or as many as nine (Fig. 56).

Stipules

In the case of many trees there are, besides the ordinary foliage leaves, special leaves close to the base of the petiole. These are the so-called stipules, which may be persistent and green and thus contribute considerably to the production of starch, as, for instance, in the case of the Hawthorn (Fig. 15), Plane, and many Willows. In other cases, however, the stipules drop off very soon after being formed, and in such a case their main function is to act as scales to the buds (Fig. 14), as in the case of the Elms, Hornbeam, Hazel, Beech. Such short-lived stipules are said to be fugacious. While perhaps one may say that the majority of dicotyledonous trees possess stipules, they are absent in the families of the Horse Chestnut, the Maple, the Ash, and in the natural order Coniferae.

Cotyledons

Another kind of leaf that deserves mention is the cotyledon, which is present in the seed and which on germination is generally the first leaf to appear above the surface of the ground (so-called epigeal cotyledons) (Figs. 57 and 58). Such cotyledons are characteristic of almost all conifers, and most other trees, but in the case of the Oak, Hazel, Horse Chestnut and Spanish Chestnut, Walnut, Maidenhair tree, etc., cotyledons never come to the surface of the ground, and such are known as hypogeal cotyledons (Fig. 59).

In the case of epigeal cotyledonary plants, the first leaves that appear after the cotyledons are the so-called primary leaves (Fig. 57), and this is the kind of leaf which is the first to show above the surface of the ground in the case of seedlings with hypogeal cotyledons. These primary leaves usually differ considerably in shape from cotyledonary leaves, and also from the ordinary foliage leaves. In the case of the Beech, for instance, they are strongly toothed along the margin, whereas the normal foliage leaf of the Beech is merely sinuous along the edge. They are simple

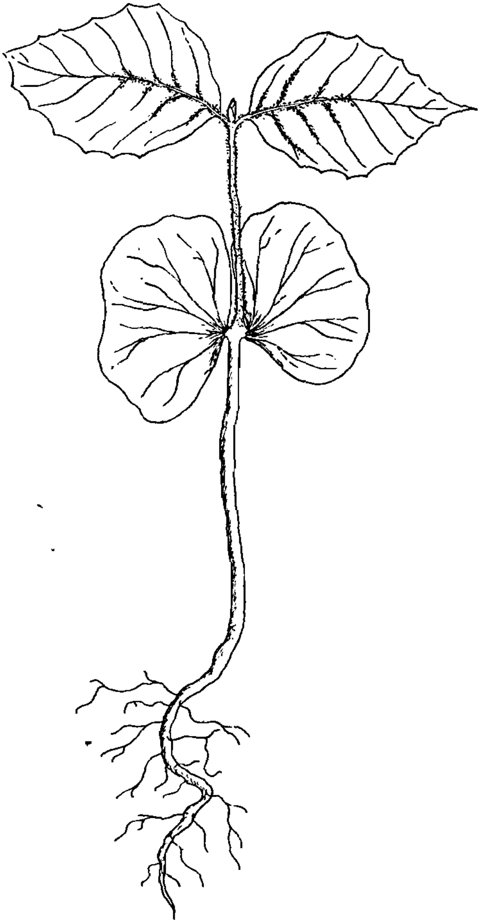

Fig. 57.—Beech Seedling (× 1, from Herbarium specimen) showing the slightly hairy axis and primary leaves and the smooth cotyledons.

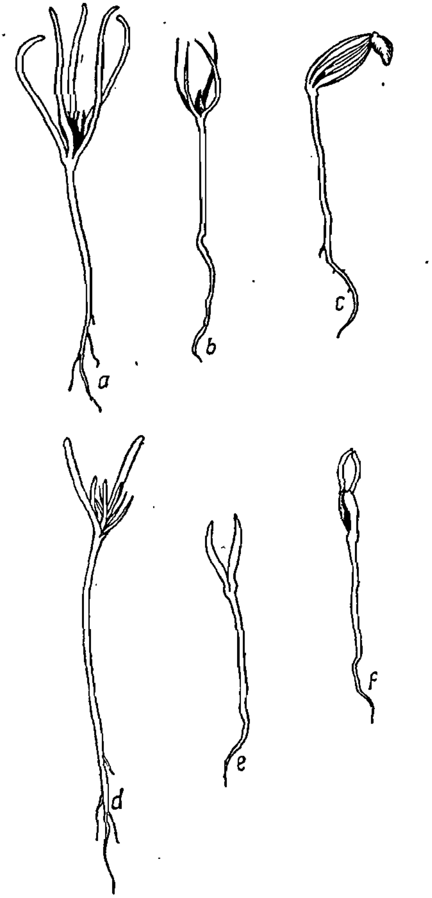

FIG. 58.—Seedlings.

a, seedling of *P. muricata*. (After Veitch.) *b*, *c*, two specimens of *Pinus silvestris* (two-thirds actual size) from material grown in S.R.E. garden. *d*, seedling of *Cupressus sempervirens*. (After Veitch.) *e*, *f*, *Thuja occidentalis*. (From Garden.)

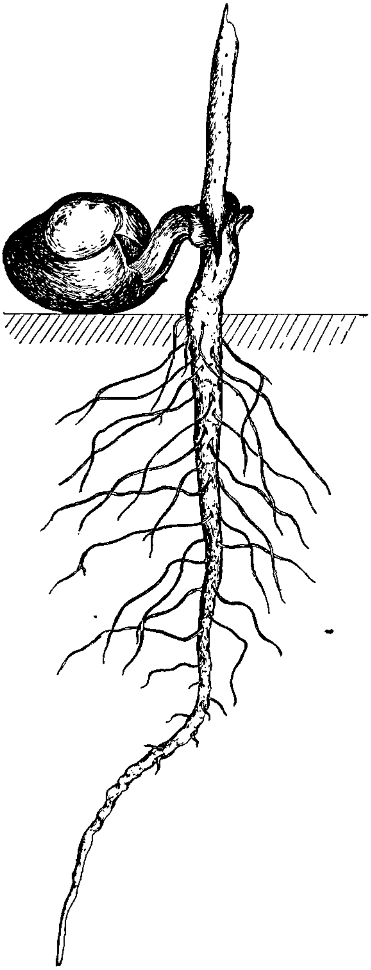

FIG. 59.—A Horse-Chestnut Seed, germinating on the surface of the ground, showing the long stalks of the cotyledons, the remains of which are retained in the husk.

in the case of Ash and *Robinia*, whereas the normal foliage leaf of these trees is a compound leaf comprising several leaflets (Fig. 60). They are oval in the case of the Sycamore, whose normal foliage is palmate (Fig. 61). The cotyledonary leaves also differ much in shape, both from ordinary foliage leaves and also from primary

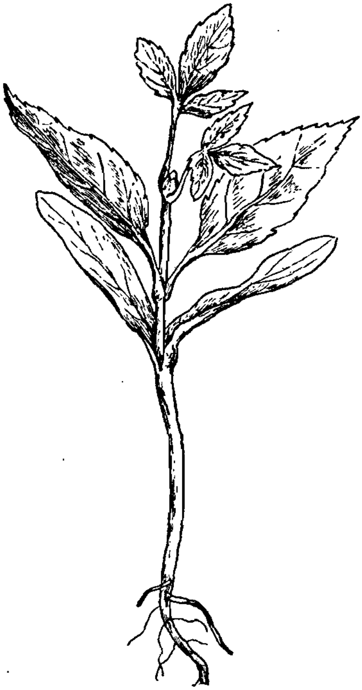

FIG. 60.—Ash Seedling. (After Willkomm.)

leaves, being ligulate in Ash and *Acer*, lobed in the Beech (Fig. 57), and round in the case of the Elm, Alder, and Hornbeam.

The Fall of the Leaf

In the case of deciduous trees the leaves fall each autumn and are renewed in the following spring; whereas in evergreens the leaves persist for two or more years. There is a sort of intermediate class between the deciduous and evergreen trees that is known as sub-evergreens, namely, trees which retain their leaves through the whole or the greater part of the winter following the season in which they are produced. Such leaves are cast in the following spring, when they are a year old. An example of this class of tree is furnished by the Lucombe Oak, which is supposed to be a hybrid between *Quercus suber* and *Quercus cerris*. Amongst shrubs and bushes examples of sub-evergreens are furnished by the common Privet, the Bramble, etc.

In the case of evergreens the persistence of the leaves depends on local conditions as well as on individual peculiarities. As a rule a tree that is in robust health will retain its leaves longer than one which is less vigorous, the Scots Pine, for example, usually retaining its leaves for only three years, but occasionally for as many as five, and

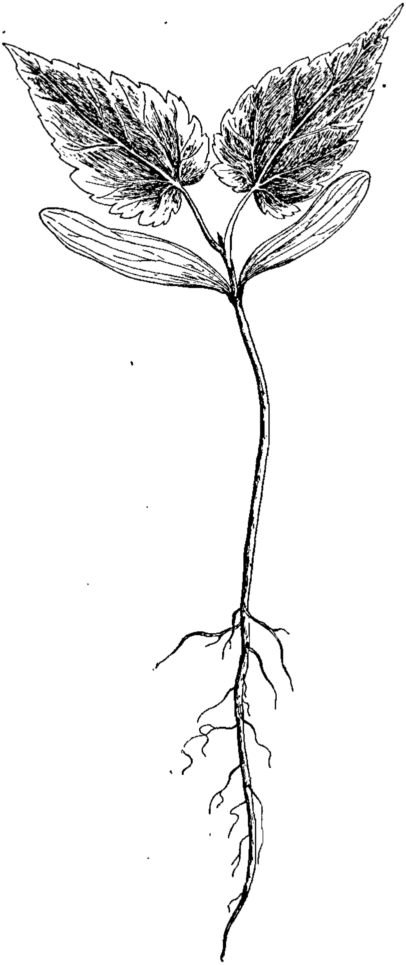

FIG. 61.—Sycamore Seedling. (× 1, from Herbarium specim

similarly with regard to many other pines. The common Spruce when young can often show leaves six years old; while Silver Firs and the Douglas Fir sometimes retain their leaves even longer.

Most conifers fall into the class of the evergreens, the most important exception being the genus *Larix*, though the Maidenhair tree and the Bald Cypress are also deciduous. The shedding of leaves is, of course, a perfectly natural process, and is brought about by the formation of a layer of corky cells near the base of the petiole. This layer—the so-called absciss layer (Fig. 18)—prevents the continuance of supplies of water passing from the stem to the leaf, and the latter consequently dies and usually falls off within a short time, though it may persist in a dead condition during the whole of the following winter, as, for example, in the case of a Beech hedge or Oak scrub. Owing to the formation of certain colouring substances leaves frequently become yellow or brown or red before falling, conspicuous instances of such changes being met with in the Elm, Cherry, Red and Scarlet Oaks, etc.

The occurrence of frost after the formation of part or all of the absciss layer will hasten the fall of the leaf, probably because the water in the intercellular spaces of the absciss layer is converted into ice with the liberation of well-known disruptive forces. If, however, the formation of the absciss layer has not progressed far when frost occurs, the leaf may be killed and

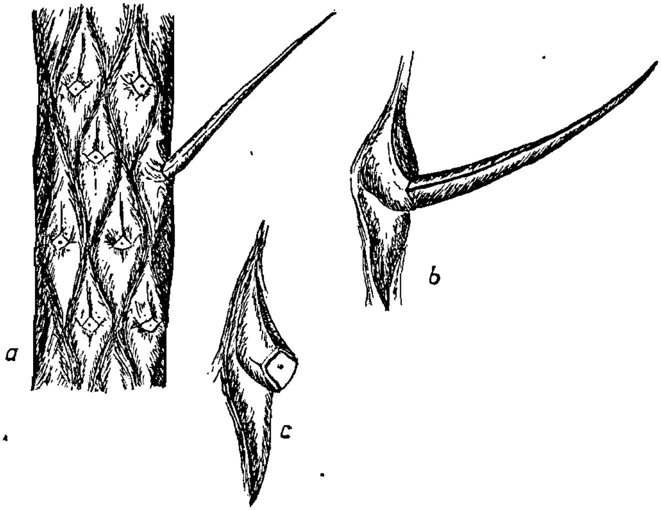

FIG. 62.—*a,* a portion of a Spruce Shoot to show persistent pulvini. *b,* leaf *in situ.* *c,* Pilvinus after leaf-fall.

subsequently no absciss layer can be formed, the result being that leaves killed by early autumn frost persist in a dead condition much longer than is the case with leaves that have not been so affected. Similarly if a branch is killed by being partially broken off in the course of the growing season, the leaves will remain attached to it far into winter.

In the case of certain trees, especially conifers, it is not the leaves but dwarf shoots that are shed, as, for example, in the case of Pines, and *Taxodium distichum*, this condition of things being known as cladoptosis.

When the petiole of a leaf is elevated on a protuberance, the latter is called a pulvinus. In the case of *Abies* and the Douglas Fir there is no such pulvinus, but it is very prominent in the genus *Picea,* so that one can recognize a shoot of *Picea* at once by the fact that the surface is quite rough owing to the presence of these pulvini (Fig. 62).

The Root

When a seed is placed in the ground the stem shoots upward and the root grows downward, both in the first instance placing themselves parallel to the radius of the earth (Fig. 59). In the case of many trees the positively geotropic character, as it is called, of the root persists for many years, when we have a pronounced case of the occurrence of a tap-root. But in the case of many trees the roots, even within a few weeks, begin to grow horizontally or obliquely, and there is little if any appearance of the tap-root-like character. It has been supposed that trees such as the Oak, Beech, Walnut, Hickory, Magnolia, etc., which show a pronounced tap-root, suffer in height-growth if the tap-root is interfered with, as it necessarily is in the process of transplanting, and it has been argued that such trees can only give their maximum height-growth where they develop from seeds sown *in situ.* This subject was investigated over 100 years ago in a Crown Forest that was maintained largely to furnish oak timber for the Navy, and the conclusion arrived at was that the removal of the tap-root did not appear to interfere in any way with height-growth.

Where trees are raised from self-sown seed, or from seed sown artificially *in situ,* the character of the root system of trees is a matter of comparatively little account; but where woods are established by plants removed from a nursery the character of the rooting may be very important, and in such a case the greatest trouble is experienced with trees possessing pronounced tap-roots. Such trees lend themselves very badly to transplantation; they are poorly provided with root fibres, and their removal from the nursery is usually associated with a high death-rate. It is partly the object of nursery treatment to induce young trees to develop a more convenient root system; and this can be best secured by lifting the plants when one or two years old and shortening the tap-root to within four or five inches of the base of the stem. When such a seedling is set out in the plant lines of the nursery to grow for another year or two it will develop a greater number of root fibres, so that when it is ultimately planted out in the forest its chances of surviving the removal will be greatly increased. With ordinary nursery stock it would, however, be too expensive to treat each plant individually, so that in practice the mere transference of seedlings when one or two years old from the seed beds to the plant lines is deemed to be sufficient to repress the tap-root and to induce the formation of a better root system. Sometimes the object is secured by the use of a sharp spade which is inserted obliquely along both sides of the line of trees, cutting the main roots at a distance of 6 to 10 inches from the collar. Many trees, however, show little if any tendency to develop a tap-root, the root system being composed exclusively of branching fibres, *e.g.* Ash, *Thuja*, etc.

It may be mentioned that whereas roots when young, and of hair-like fineness, pursue a zig-zag course, they contract along their length when fairly fixed in the soil and become quite taut, so that the tree becomes much more firmly anchored to the ground.

Acclimatization

When young, trees of course have their roots disposed more closely to the surface of the ground than later in life, and as shallow roots come more quickly under the influence of the sun in spring, young trees generally start to grow, and produce leaves and shoots earlier in the season, than older trees whose roots, being deeper in the soil, are further removed from the influence of atmospheric heat. As a consequence, young trees are more liable to be injured by late frost, although this danger also depends on the fact that temperatures are lower near the surface of the ground than higher up. It is well known that many exotic trees, which may be difficult to establish owing to special susceptibility to frost, become fairly acclimatized if they can survive the first few years of their existence. This is because later on they do not come into leaf so early in spring, and, moreover, their crowns are by this time raised above the dangerous frost zone.

Adventitious Roots

Not only do trees possess ordinary roots, but practically all of them can be induced to develop adventitious roots, the kind of root which appears upon a cutting or layer (Fig. 63). Such roots are, therefore, of great importance in connexion with certain methods of propagation, it being more convenient in many cases to raise young stock by layers or cuttings than by sowing seed. Some trees rarely mature their seed in this country, as, for instance, the English Elm ; while in certain other cases the trees may be only represented by unisexual individuals, so that in their case the production of seed is excluded. This applies to the Lombardy Poplar (which is only known in this country in the male form) and to the so-called Babylonian or Napoleon's Willow, the specimens of which in this country are all female. Willows and Poplars are generally raised from cuttings, for although many of them produce seed, it retains its power of germination for but a short time, and, moreover, is rather fastidious as regards the conditions of germination. Other trees, again, such as the English Elm, are almost entirely raised from root suckers ; while in other cases, notably the Lime, the method of propagation by layering is generally adopted. When the shoot that comes from a stool is bent down and a portion laid beneath the soil, it may produce adventitious roots at that point without any further trouble. But some trees are slow to produce adventitious roots, and the process can

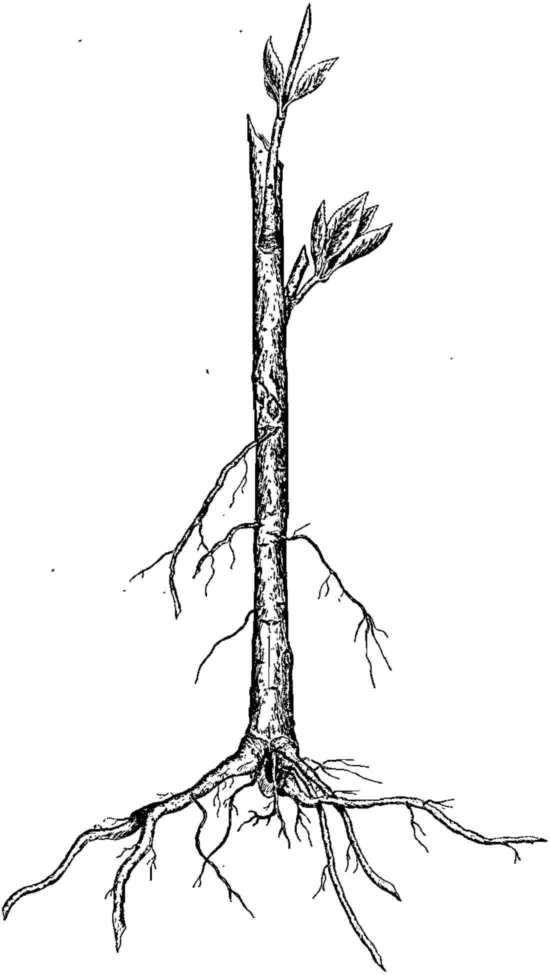

FIG. 63.—Cutting showing Adventitious Roots produced by callus at cut end, and a few elsewhere.

be hastened by binding string or wire tightly round the shoot at the point covered by the soil, or a ring of bark may be removed, or, as is actually done in practice, the shoot may be twisted on its own axis, so as to rupture a large number of the bast elements. In all these cases the result is that the downward movement of elaborated plant food is interrupted at the point which is bound, girdled or twisted, with the result that such material accumulates immediately above the point of disturbance, and adventitious roots are thereby induced to develop.

Mycorrhiza

It is by means of root hairs, which are unilateral outgrowths of epidermal cells, that a tree —in common with other plants—absorbs water and mineral substances from the soil. In some cases, however, the root hairs are suppressed by a fungal growth which itself undertakes the transference of water and nutriment from the soil to the root, and roots associated with such fungal growth are called mycorrhiza. This condition of things is widely distributed in the vegetable kingdom, but is commonest in plants growing in soil rich in humus, e.g. *Molinia coerulea*, a common grass of heaths and hills, most if not all terrestrial Orchids, many Gentians, also Bog Myrtle, Heaths, and *Vaccinium*, a genus that includes Whortleberry, Cowberry, etc. Amongst trees mycorrhiza are also very abundant, and take two forms, one where the mycelium of the fungus forms a close web on the surface of the root, hyphae being sent into the soil in search of water and nourishment, which are conveyed to the tree root (Fig. 64). While the bulk of the fungal growth is on the outside of the root, a certain number of strands enter the root itself and are disposed between the cells of the cortex; such mycorrhiza bear the name ectotrophic, and this is the form that prevails on the roots of the genus *Picea* (Fig. 64). The other type of

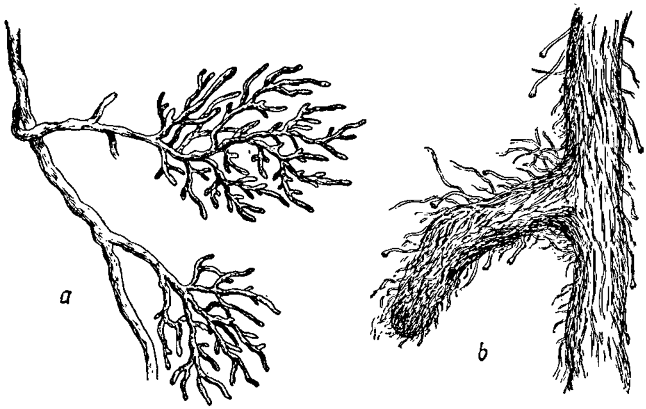

FIG. 64.—Mycorrhiza. *a*, the much-branched roots of Spruce, which are invested with fungal hyphae.

b, part of Spruce root showing investment of fungal hyphae.

mycorrhiza is known as endotrophic, and here the mycelium and hyphae invade the lumina of the root cells, the hyphae that are sent out into the soil being few, if any (Fig. 65). Endotrophic mycorrhiza characterize the following species and genera: *Pinus montana*, *Juniperus*, *Taxus*, *Thuya*, *Cryptomeria*, *Podocarpus*, *Ericaceae*, *Orchidaceae*, *Empetrum*, *Gentianaceae* (Fig. 65 (*b*)). It not infrequently happens that both forms are

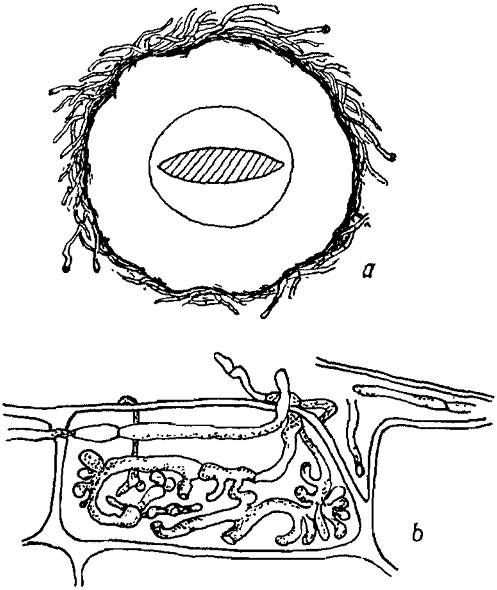

Fig. 65.—Mycorrhiza. *a*, diagrammatic T.S. of Spruce root with investing hyphae.

b, a single superficial cell of young root of Common Heather with endotrophic fungus. After Rayner.

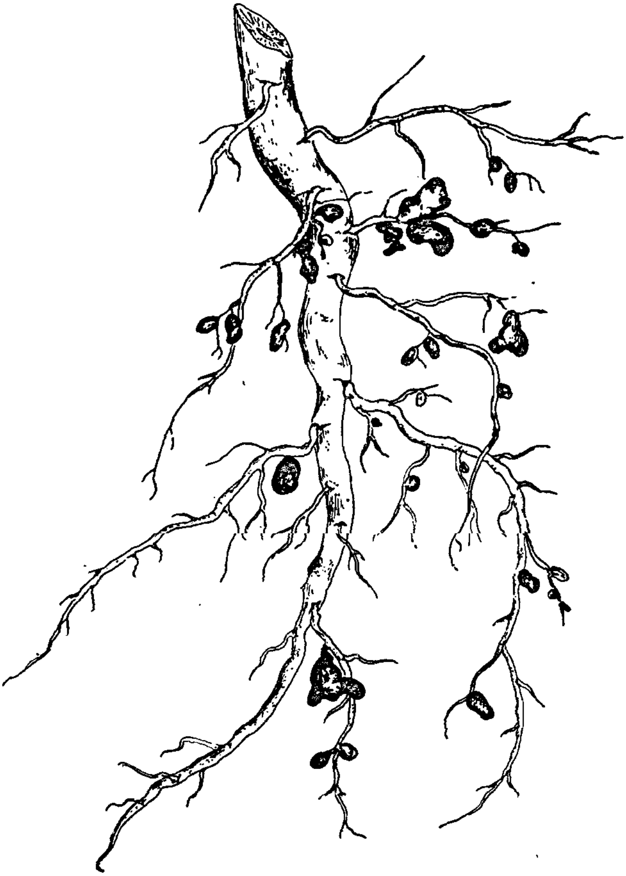

FIG. 66.—Leguminous Roots (Broom) showing nodules. (Actual specimen, × 1.)

to be found on the same plant, in fact it may be said that this is generally the case.

The particular species of fungus which enters into such relationship with the roots of trees and other plants has only in a few cases been determined, but in a general way it may be said that the association is much the same as the symbiotic relationship that exists between the natural order *Leguminosae* and certain bacteria (Fig. 66). It is well known that the roots of species of *Leguminosae* are plentifully provided with nodular growths, and when these are examined under the high power of the microscope they are found to be colonies of bacteria, which are able to work up the free nitrogen of the air into organic combinations, the latter being absorbed into the roots of the particular species of *Leguminosae*.

The uses of mycorrhiza are said to be (1) to undertake the supply of water and mineral matter to the plant (Frank and Stahl), the endotrophic mycorrhiza also fixing and supplying free nitrogen (Frank, Nobbe, and Hiltner), which as proteid is afterwards digested and assimilated by the higher plant after the analogy of insectivorous plants ; (2) to work up humus nitrogen into proteids and to pass them on to the plant (Tubeuf). It is believed that the ectotropic mycorrhiza are most concerned with this process.

As has been said, mycorrhiza are associated with the disappearance of root hairs, so much so, in fact, that in some trees (e.g. *Pinus montana*) root hairs are extremely rare. P. C. Müller advances the theory that such a plant as *Picea*, with few if any endotrophic mycorrhiza, grows well in soil where humus is scarce, but thrives badly in soils which are rich in humus. According to Müller the bad growth of *Picea* in peaty soil is due to the fact that the tree cannot successfully compete with the abundant fungus mycelia which are found there; whereas trees with endotrophic mycorrhiza, e.g. *Pinus montana*, can grow well in the latter case. He calls attention to the yellow stunted character of the Spruces that have been planted on the heaths of Denmark, when they are in pure woods; whereas this tree grows successfully if mixed with 50 per cent. of *Pinus montana*. The theory is that *Pinus montana* can appropriate abundant nitrogen from the peat, and can work it up for the benefit of the associated Spruces. Plants growing on heaths, e.g. *Molinea coerulea*, have generally abundant endotrophic mycorrhiza, and hence are at a great advantage compared with trees possessing the other kind of mycorrhiza, *e.g.* the Spruce. It seems to have been proved that certain trees may or may not possess mycorrhiza, in which case they are called facultative mycorrhiza plants, e.g. *Pinus*, *Cupuliferae*, etc. These have abundant root hairs in soil poor in humus; whereas in peat they develop mycorrhiza and the root hairs are suppressed.

In the case of most conifers the mycorrhiza are much branched, a condition of things known as dichotomous; whereas in other cases the mycorrhiza are characterized by great numbers of short branches, the whole aggregation reminding one of a bunch of currants or grapes, and such mycorrhiza are known as racemose. Racemose mycorrhiza are very common on the roots of the Alder, where they often appear as large, warty outgrowths, and the same condition of things is met with in *Eleagnus*, Sea Buckthorn, Bog Myrtle, etc.

It is well known that certain plants, both trees and garden flowers, are very difficult to establish in new soil, and it is believed that this difficulty is often connected with the absence of the particular fungus on which the species depends for nourishment. The difficulty will be got over in most cases if a small quantity of soil from the natural habitat of the plant is intermixed with the soil of its new position. This was recognized more than 100 years ago, for we are told that the fishing boats that plied on the Newfoundland

Banks often brought young conifers to England, and that the importers were always careful to *fetch a certain amount of Newfoundland soil, or* otherwise the trees established themselves in this country with difficulty.

Flowers, Fruits, and Seeds

Flowers are shoots modified to serve the purposes of reproduction. That this is so is best proved by examining a cone, say of Larch or *Cryptomeria*, which shows prolification. This condition of things is shown in Fig. 67, where it will be seen that a shoot carrying foliage leaves appears at the end of the cone. The same sort of thing is sometimes seen in the Pear, where from the apex of the fruit there emerges a leafy shoot.

A complete flower consists of four envelopes, namely, the calyx, with its constituent sepals; the corolla, comprising the petals; the androecium, with its stamens; and the gynoecium, with the carpel or carpels (Fig. 68). In many cases, however, the flower is not complete, and then we may have the following conditions: (*a*) where there is neither corolla nor calyx the flowers are said to be achlamydeous or naked, a condition of things found in *Salix*, the Ash, the female flower of the Birch and of the Alder, also

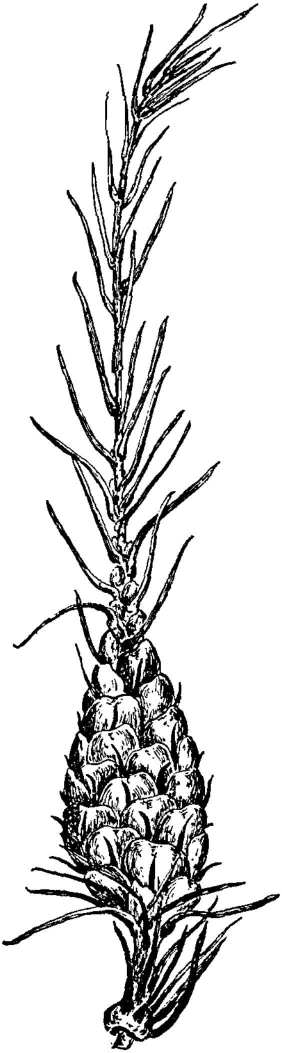

FIG. 67.—A prolificating Larch-cone. (Actual size).
(From actual specimen.)

in *Populus* and conifers (Figs. 69, 70). (*b*) Frequently there is only one envelope present, usually the calyx, when the flower is said to be monochlamydeous, a condition of things represented by the Elm (Fig. 70), Oak, Beech, Hazel, Spanish Chestnut, Walnut, Hornbeam, and the male flower of the Alder and Birch. The term perianth is applied to the case where there are only stamens present, the term perigone being employed when there is only a pistil or pistils. (*c*) Where the pistil and stamens are in

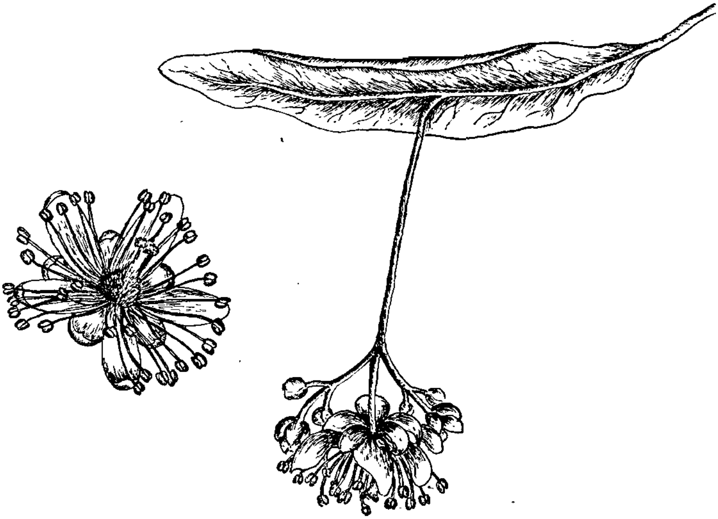

FIG. 68.—Lime.

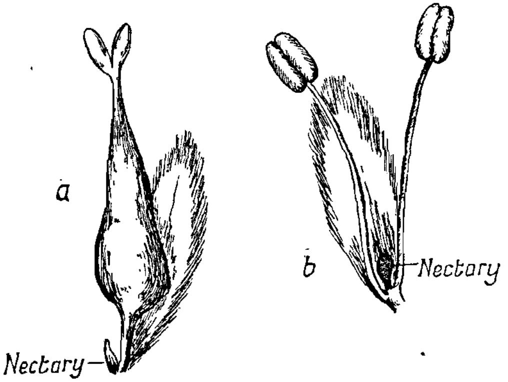

FIG. 69.—Willow. *a*, Carpellary flower, × 4. *b*, staminate flower, × 4.

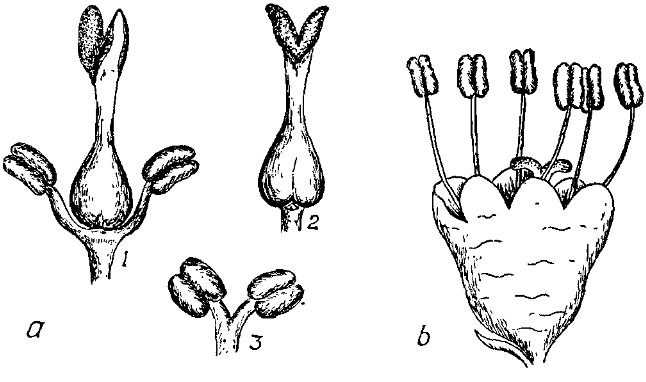

FIG. 70.—Ash. *a*. 1, Monoclinous flower. 2, Carpellary flower, 3, Staminate flower.
b. An Elm flower much enlarged.

separate flowers, this condition of things is called unisexual or diclinous, and is represented in all the conifers, and in many other cases, such as the Birch, Willow, and Poplar. (*d*) Where both sexes are met with on the same plant, though in separate flowers, the arrangement is called monoecious, as, for instance, in the Beech, Hornbeam, Spanish Chestnut, Alder, Oak, Hazel, Spruce, Pines, *Abies*, *Larix*, Walnut, Hickory. (*e*) The other state of things is rarer, namely, where one only gets one sex represented on one plant (dioecious), *e.g.* Willow, Poplar, Yew, and *Araucaria*. (*f*) The hermaphroditic condition is

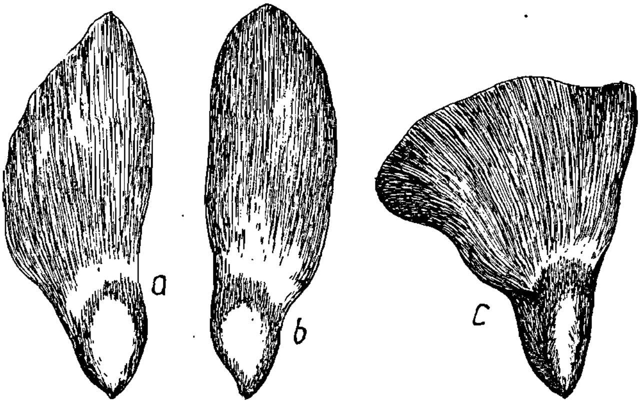

FIG. 71.—*a*, Seeds (with wing), *Pinus silvestris*, ×4. *b*, *Picea excelsa*, ×4. *c*, *Abies nobilis*, showing inturned portion of wing holding seed, ×2.

where both sexes are represented in the same flower, as, for instance, in the Horse Chestnut, Lime, *Rosaceae*, etc. (Fig. 68).

Frequently the seeds or fruits are provided with wings so that they may be blown by the wind and thus dispersed. Most conifer seeds are winged (Fig. 71), and the fruit of the Ash, Birch, Alder, Elm, and Maple is also provided with a winged appendage.

Germination

When seed is placed under certain conditions it germinates, the essential conditions being air, moisture, and heat. Moisture induces the seed to swell and produces a ferment which causes the reserve materials to dissolve, so that they can be easily transported where required. The result is that the embryo unfolds and the cotyledons are either left below ground or they come to the surface. In most cases seed which is sown in spring germinates at once, but there are certain seeds which if kept till spring do not germinate for a year. This is characteristic of the seed of the Juniper, Yew, Hawthorn, *Prunus*, Lime, Holly, and Ash. Such seed is usually stratified, that is to say it is put between layers of straw and covered with soil, and after a year it is separated from the soil and sown, when it germinates at once. Frequently such preparation for germination is effected by mixing the seed with some sand and leaving it in a heap during the summer. In this way nurserymen usually treat Hawthorn seed. Certain seed will not retain its power of germination beyond the spring of the year following that in which it is produced. This is so in the case of Birch, Hazel, Oak, Beech, Chestnut, Walnut, and *Abies*. On the other hand, some seed will retain its power of germination for years, *e.g.* Scots Pine seed if kept in the cone will retain its capacity to germinate practically unimpaired for at least three years. Some seed, on the other hand, will only retain its germination for a few days; this applies to the Poplar and Willow.

Importance of Origin of Seed

It is very important that trees well grown and sound should be used for the production of seed. A great deal of work has been done on this subject of late years, especially in Austria and Switzerland, and it is proved incontestably that the following characters are transmitted from the parents to the offspring by inheritance, namely: (*a*) The proportion of root to stem. Trees grown at high altitudes develop strong roots so as to be able to withstand gales, and this character is transmitted by inheritance. (*b*) Rate of growth. (*c*) Energy of growth, that is to say whether spread over a short or long period of the year. (*d*) Twisted growth, gnarled and crooked stems. (*e*) Excessive branching of Scots Pine is also transmitted in this way. (*f*) Predisposition to leaf-casting is another character which is inherited.

Where a forester gathers his own seed he can, of course, select the parent tree with great care, but he has little control over its origin when he is dealing with commercial seed. There is a *great temptation on the part of collectors to take* seed that is most easily obtained, and consequently seed is often collected from trees that are dwarfed, and this character of dwarfness is apt to be reproduced in the offspring.

Ascent and Descent of Sap in Trees

No satisfactory explanation has been arrived at as to the way in which water rises from the ground to the top of a tree. Root pressure has something to do with this movement, and it has been found that water will exude from the cut surface of a stem 8 or 10 feet above the ground, and such exudation can only be explained by root pressure. Capillarity has also something to do with the ascent of sap, and everyone knows that water will rise against the force of gravity in a very small tube. Then, again, the evapora-

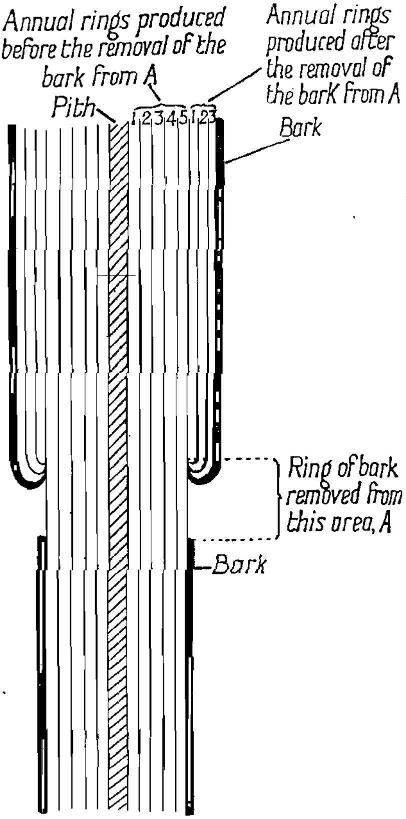
Annual rings produced before the removal of the bark from A
Annual rings produced after the removal of the bark from A
Pith
1 2 3 4 5 1 2 3
Bark
Ring of bark removed from this area, A
Bark

FIG. 72.—The effects of ringing (diagrammatic.)

tion of water from the leaves creates a vacuum and water is induced to rise from a point situated lower down. More recently a pulsating movement has been discovered in plants, which may have something to do with the rise of water. But it cannot be said that any one of these explanations is quite satisfactory.

While the cause of the ascent of water is not quite clear, the path which it follows is well understood. This is best shown by a girdling or ringing experiment. If a young tree is taken in spring and a girdle of bark (in the popular sense of the term) is removed from it, it is found that the removal of the bark does not interfere with the rise of water (Fig. 72). This shows that the water rises in the wood and not in the bark. In point of fact, the water rises in the outer rings of the wood, the heart-wood taking no part in the transportation of water. If after a few years' growth such a tree is felled and cut up, it will be found that growth in thickness has taken place above the point where the bark was removed and not below, which shows that what moves up from the soil is not directly concerned in the production of wood, but that the formative material moves down the stem outside the cambium layer.

Trees may remain alive for many years after they are girdled, death ultimately taking place owing to an attack of fungi on the exposed portion, or owing to the fact that the roots cease to function, for the latter are as dependent as is the cambium on what comes down from above. While wood that is exposed becomes dry and lifeless, it is found that if a waterproof substance is placed on the girdled portion immediately the bark is removed, the cambium will continue to function all over the exposed surface, and will even form fresh bark.

The Identification of Timbers

When a piece of wood is placed in one's hands for the purpose of identification, the first thing to do is to decide whether it is a piece of hardwood or a conifer. By the aid of a pocket lens one can make out the vessels in the hardwood, and if these are present then it cannot be a piece of conifer. In many cases the vessels are quite distinct, although in some instances they are very fine. One can frequently improve matters by taking a thin section and holding it up to the light, when the vessels will show up more conspicuously. As soon as it is decided that a piece of wood is a hardwood, the generic identification can be made out by the naked eye, especially if assisted by a pocket lens. The next step is to separate off a considerable number of species by the way the vessels are distributed in the ring. Certain species have the vessels in the spring wood in large numbers and of large size, and this applies to the Ash, Elm, Oak, Spanish Chestnut, *Ailanthus* and *Robinia*, all of which possess what is called a pore zone. In order to differentiate these six genera we must look for other characters. In the Ash duramen is present, which is also the case in the other five genera-

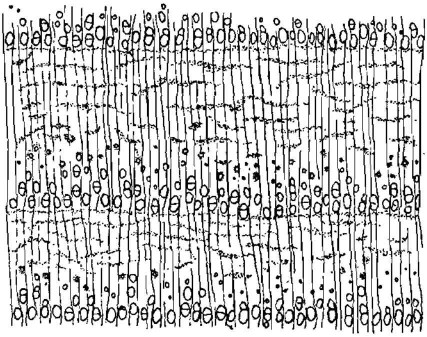

FIG. 73.—Ash (quickly grown). × 10.

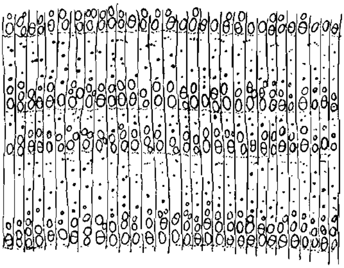

FIG. 74.—Ash (slowly grown). × 10.

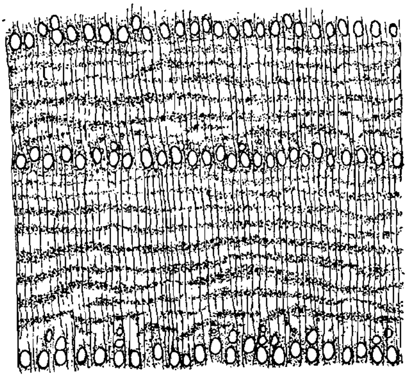

FIG. 75.—Elm. × 10.

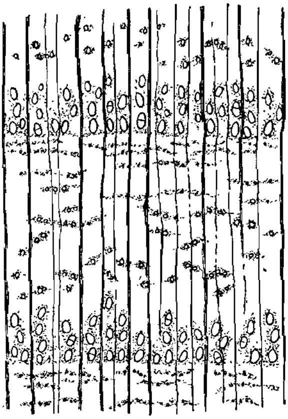

FIG. 76.—Ailanthus. × 10.

In the case of a broad ring the vessels in the autumn wood of Ash are arranged in peripheral zones (Fig. 73), but this character is absent from a slow-grown piece of Ash (Fig. 74). The rays

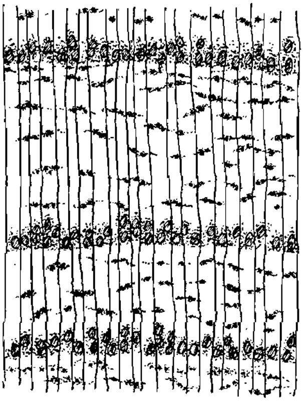

Fig. 77.—Robinia. × 10.

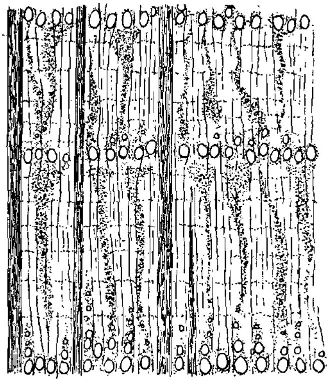

Fig. 78.—Oak. × 10.

are very fine and the duramen is not very conspicuous and is surrounded by a broad zone of sap wood. It is a tough and pliable wood that is used largely for making tool handles, carriage building, and cheap cabinet work, such as bedroom furniture and the like.

In the Elm (Fig. 75) the vessels of the autumn wood are arranged roughly in concentric bands, and the duramen is much darker and broader than in the case of the Ash. The rays, however, are equally fine. The wood is tough and rather hard, and is used for wheels, carriages, coffins, weatherboards, and doors.

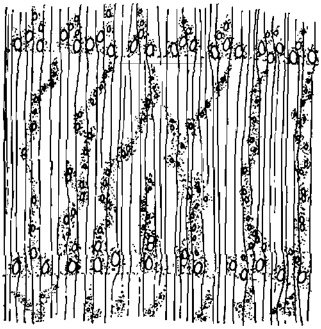

FIG. 79.—Spanish Chestnut. × 10.

In *Ailanthus glandulosa* the vessels in the autumn wood are also arranged in peripheral lines, but are not so continuous as in Elm (Fig. 76).

This tree, which is a native of China, grows very fast in this country, and is quite hardy in the southern parts of England. It forms impressive foliage, its leaves often reaching a length of four feet.

Robinia pseudacacia (Fig. 77). This is also hardy in the south of England, where it grows

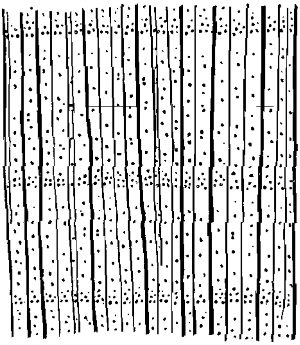

Fig. 80.—Cherry. × 10.

well on sandy soil. The duramen is very dark in colour, and the vessels are plugged with tyloses. Its timber is very useful for outdoor purposes, as also for making ships' pins.

In the case of the Oak and the Spanish Chestnut the vessels are arranged in zones, but the Oak is at once distinguished by possessing a large proportion of very broad rays (Fig. 78). The duramen in both cases is much the same in colour, and in both also the small vessels in the autumn wood are arranged in radial lines. The wood is hard, heavy, tough and durable, and it is used for waggons, fences, boat-building, furniture, wainscoting, and high-class structures.

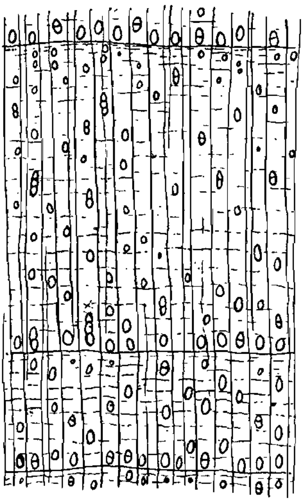

FIG. 81.—Walnut. × 10.

Spanish Chestnut (*Fig.* 79) is superficially very like Oak, but the fact that it possesses only very fine medullary rays—so fine that they can hardly be distinguished by the naked eye—at once differentiates it from the other timber. It is used for very much the same purposes as Oak, but when young is more durable.

The next group contains timbers in which the vessels of the spring wood are much more numerous but not larger than in the autumn wood. In Cherry (Fig. 80) the timber is pale yellow in colour, the medullary rays being very fine but distinct.

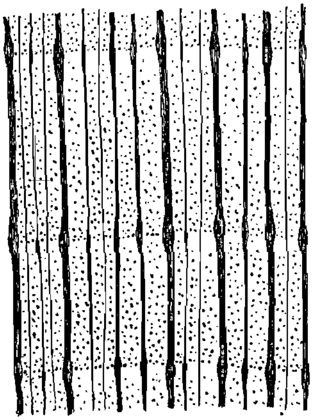

FIG. 82.—Plane. × 10.

Another large group of timbers is provided with spring wood, where the vessels are neither conspicuously larger nor more numerous than in the autumn wood. Into this group there falls the Walnut (Fig. 81), which has large vessels, which, however, are rather scarce. All the medullary rays are fine. The wood is dark, fairly hard and fairly heavy. It is used principally for gunstocks and high-class cabinet work.

Woods where the vessels are scarcely visible to the naked eye comprise :

The Plane Tree (*Platanus*) where the rays are numerous and broad (Fig. 82). No duramen is present, the wood being brownish-white in colour and not heavy. It is employed for fancy woodwork.

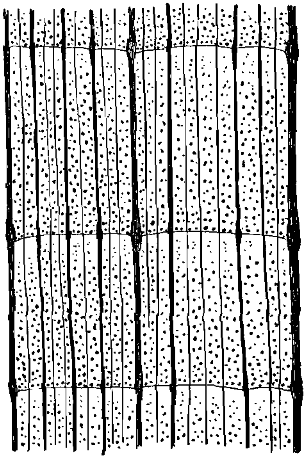

FIG. 83.—Beech. × 10.

Beech (Fig. 83) is rather like the Plane. Here the rays are of varying breadth, some being very conspicuous. They widen out somewhat in crossing the boundary of two rings. The Beech contains no true duramen, although the heartwood is often of a darker colour, which, however, is due to incipient decay. In colour the wood is reddish-white, and it is very hard and heavy. It is an important wood from the point of view of firewood, the treads of stairs, furniture, boot trees and lasts; and also sleepers, if creosoted.

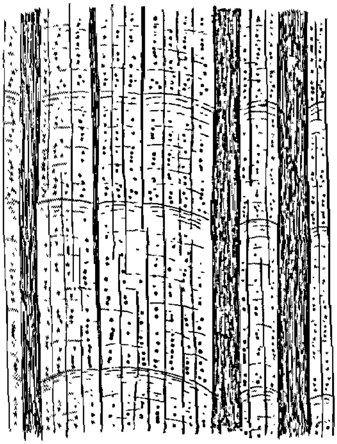

FIG. 84.—Hornbeam. × 10.

Hornbeam (Fig. 84) resembles Beech, but is whiter, the rings being sinuous, and their outline rather indistinct. The vessels are inclined to be radially arranged, and no duramen is present. It is a hard and tough timber, used for mallets, boot trees, wheel cogs, and so on.

Hazel also falls into this group (Fig. 85). The colour of the timber is reddish, without duramen.

It is chiefly grown as coppice, and furnishes material for crates, hurdles, barrel hoops, etc.

Alder (Fig. 86) superficially resembles Beech, but the broad rays are very scarce and sometimes absent. It is reddish in colour. The rings are obscure, the timber is soft and light. It is frequently marked by pith flecks, which are the work of the larvae of an insect in the cambium. There is no duramen present. It is used in the manufacture of clogs, cigar boxes, bobbins, and at one time was very important in the manufacture of black gunpowder.

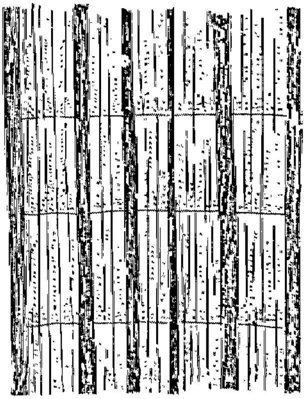

FIG. 85.—Hazel. × 10.

Woods where the rays are fine, although not all alike fine, and are sharply defined and distinctly visible, form a group which includes

Sycamore and Maples generally (Fig. 87). The wood of Sycamore is white, lustrous, tough, moderately hard, and heavy. There is no duramen present. It is employed in turnery, fancy woodwork, calico mill rollers, cabinet-making, dairy utensils, musical instruments, etc.

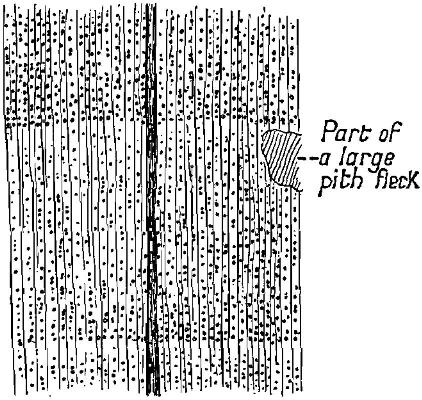

Fig. 86.—Alder. × 10.

In Lime (Fig. 88) there is no duramen present; its rings are rather indistinct. The wood is yellowish-white, soft, light and lustrous, and is employed in turnery, for fancy boxes, mill-boards, musical instruments and wood-carving.

The Holly (Fig. 89) has no duramen. The wood is white and frequently tinged with green. It is hard and heavy, and is used in turnery and fancy woodwork.

In the Pear and Apple (Fig. 90) the rays are practically invisible to the naked eye. These

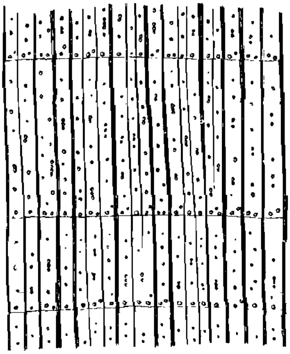

FIG. 87.—Sycamore. × 10.

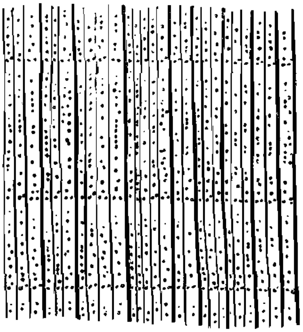

FIG. 88.—Lime. × 10.

woods are indistinguishable except under a compound microscope. The medullary rays per square millimetre are slightly greater in the Pear than in the Apple (Jones). The Pear is valuable for making mathematical instruments. It is brownish-white, heavy, and difficult to split.

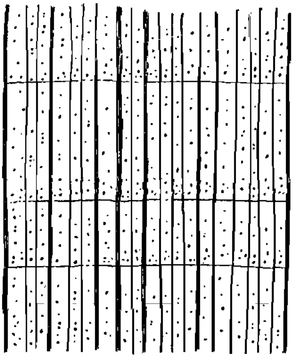

FIG. 89.—Holly. × 10.

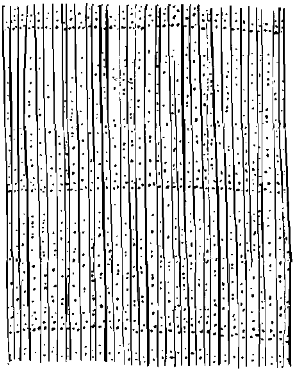

FIG. 90.—Apple. × 10.

Hawthorn is another wood which closely resembles Apple and Pear. Pith flecks are present. It is reddish-white in colour, very tough, and used in turnery.

Birch (Fig. 91) has no duramen. It is reddish-white in colour, often with pith flecks, fairly heavy, hard, tough. It is principally used for bobbin wood, and also for making light furniture and plywood.

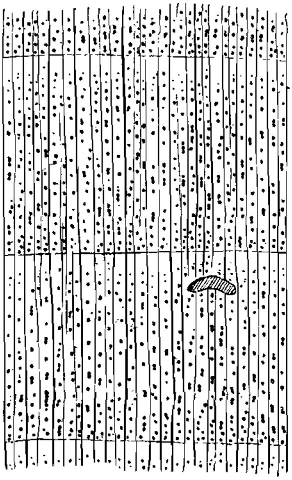

FIG. 91.—Birch. × 10.

Boxwood is met with on the hills of Northern India and on the chalk hills of Surrey, and is a very common plant in the Mediterranean area. It is hard, heavy, even grained, and

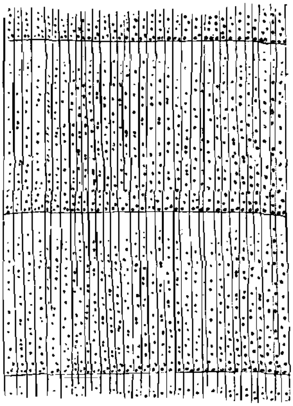

FIG. 92.—Horse Chestnut. × 10.

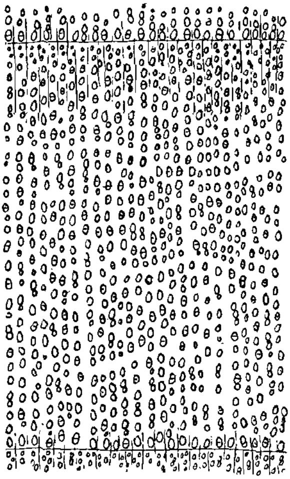

FIG. 93.—Goat Willow. (From a very porous, quickly grown specimen.) × 10.

homogeneous. It is used for wood-engraving, croquet balls, bowls, fancy woodwork, etc.

Then there are certain other timbers which fall into this group, such as Horse Chestnut (Fig. 92), with no duramen. It is white, soft, fairly tough, but not durable. The wood is used for lining carts, barrows, blind wood and furniture, packing cases, and so on.

Willows (Fig. 93) generally possess duramen. The central wood is reddish in colour, the sap wood being white. The timber is light, soft, tough, and is used for cricket bats, blind wood, lining of carts, brake blocks, packing cases, etc.

Poplars usually show duramen. The wood is soft, light, white, and is used for packing cases, matches, blind wood, butter boxes, etc.

Summary of the Naked Eye (Macroscopic) Characters of European Hardwood Timbers

I. SPRING WOOD WITH LARGE VESSELS

(*a*) Vessels in autumn wood generally equally distributed.

Ash (*Fraxinus excelsior*). With duramen. Rays fine.

(*b*) Vessels in autumn wood in roughly concentric bands.

Elm (*Ulmus campestris*, *U. montana*). With duramen. Rays fine.

The Locust tree (*Robinia pseudacacia*). The vessels of duramen are plugged with tylosis.

Ailanthus glandulosa has a strong resemblance to Ash, but it is much more brittle. In the autumn wood the vessels are arranged in peripheral lines, but do not, however, run so continuously as in Elm. The duramen is much less conspicuous than in Elm.

(*c*) Vessels in autumn wood arranged radially.

(1) Some rays broad, most fine.

English Oak (*Quercus pedunculata*, *Q. sessiliflora*). With duramen.

(2) All rays fine.

Spanish Chestnut (*Castanea vesca*).

II. THE VESSELS ARE NOT LARGER, BUT MORE NUMEROUS THAN IN AUTUMN WOOD

This group includes Cherry, with a poorly differentiated duramen.

III. SPRING WOOD WITH NO MORE OR LARGER VESSELS THAN THE AUTUMN WOOD

(*a*) Vessels large and scarce.

Walnut (*Juglans regia*). With duramen. Rays fine. Wood dark, often "watered" (*b*) Vessels scarcely visible.

(1) Rays numerous and broad.

The Plane (e.g. *Platanus acerifolia*). No duramen. Wood brownish-white.

(2) Rays of varying breadth.

The Beech (*Fagus silvatica*). No true duramen. Wood reddish-white, hard, heavy.

Hornbeam (*Carpinus betulus*). Resembles Beech, but whiter. Rings sinuous, rather indistinct. Vessels inclined to a radial arrangement. No duramen.

In Hazel (*Corylus avellana*) the wood is reddish in colour, and there is no duramen. The vessels in the autumn wood are arranged in radial lines.

(3) Broad rays very scarce, sometimes absent.

Alder (*Alnus glutinosa*). Wood reddish, rings obscure. Soft, light. Often "pith flecks." No duramen.

(4) All rays fine, though not all alike fine, but sharply defined and distinctly visible.

Sycamore (*Acer pseudo-platanus*) and Maples generally. Wood white, lustrous, tough, moderately hard and heavy. No duramen.

Lime (*Tilia europaea*). No duramen. Rings rather indistinct. Wood yellowish-white. Soft, light, not lustrous.

Holly (*Ilex aquifolium*). No duramen. Wood white, often tinged with green. Hard, heavy.

(5) Rays practically invisible to the naked eye.

(*a*) Hard woods.

Pear (*Pyrus communis*). No duramen.

Apple (*Pyrus malus*). With duramen.

These woods agree closely in character. Both are brownish-white, heavy, hard, difficult to split.

Hawthorn (*Crataegus oxyacantha*). No duramen. Usually "pith flecks." Reddish-white, heavy, hard, tough.

Rowan or Mountain Ash (*Sorbus aucuparia*).

White Beam (*Sorbus aria*). Both with duramen.

Birch (*Betula alba*). No duramen.

Yellowish - white. Often "pith flecks." Fairly heavy, hard, tough.

Box (*Buxus sempervirens*). No duramen. Hard, heavy, even-grained, homogeneous.

(*b*) Soft woods.

Horse Chestnut (*Aesculus hippocastanum*). No duramen. White, soft, non-durable, but fairly tough.

Willow (genus *Salix*). With duramen. Central wood reddish, sapwood whiter. Light, soft, rough, elastic.

Poplars (genus *Populus*). Most show duramen. The wood is soft, white, light.

Characteristics of Coniferous Timbers

If a block of wood that we are examining should prove to be that of a conifer, we may make an attempt to identify it with the naked eye or with the aid of a pocket lens, but such means of identification will not lead us very far. The presence or absence of duramen will assist us, Pines, Larch, and Douglas Fir all having duramen, whereas Spruce and Silver Fir have not got this character. Then the presence or absence of resin ducts will help us somewhat in identification.

These can be made out with the aid of a pocket lens, on a good cross-section, when they appear as little brown spots. Again, the disposition of the knots is of assistance, the Pines generally having the branches in whorls, while the knots are also in definite zones. Sooner or later we have to resort to the use of a compound microscope to assist us, and even then we can only identify the main genera and not the species.

In the case of the Pines, which are divided into three groups, namely two-leaved, three-leaved, and five-leaved Pines, there are always tracheids in the rays and resin ducts in the wood.

The Two-Leaved Pines

In the case of the two-leaved Pines, which include the Scots Pine, the Cluster Pine, and the Corsican Pine, *Pinus montana*, *Pinus Pinea*, etc., the parenchymatous cells of the rays have only one pit to each vertical tracheid, unless where the ends of parenchymatous cells happen to coincide with a vertical tracheid, when there is one on each side of the septum.

Of the various species of this group, Scots Pine (Fig. 94) is the most important. It is found all over Europe and most of northern Asia, and is imported into this country from the Baltic under the name of Baltic Redwood, or Yellow Deal. It is largely used for house carpentry, sleepers, paving blocks, telegraph poles, masts, boat-building, fencing, pit props, etc. *Pinus pinaster* is met with in the whole of the Mediterranean basin, and has been extensively planted in the Landes, where it is largely tapped for resin. A large quantity of pit props are imported from that region into South Wales. The timber is coarser than that of Scots Pine, and is used for rougher carpentry. The Corsican Pine with its

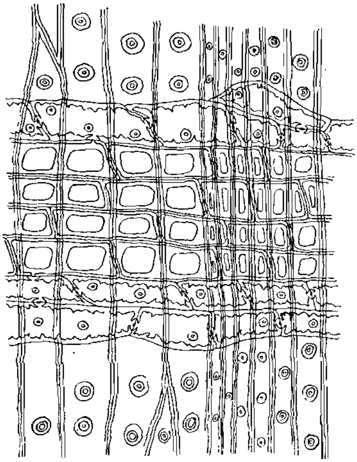

FIG. 94.—L.R.S. *Pinus sylvestris*. × 400.

Note the large pits in the ray parenchyma of which there is only one normally to each vertical tracheid, but in the second row there is an instance of two occurring.

varieties is met with in Corsica, in the Adriatic, etc. It is employed in carpentry and sleepers, and is tapped for resin. *Pinus Pinea* is found in Northern Italy, where it is used for rough carpentry, but is chiefly valuable for its seed, which is an important article of human consumption.

From North America we get *Pinus resinosa*, the Red Pine or Norway Pine, so called because it is met with near Norway, in New England, and it extends as far west as the Prairies. It very closely resembles Scots Pine in character, is very resinous, and is used for flooring, piles, and so on.

Another North-American species is *Pinus Banksiana*, the Jack Pine. It extends all through Canada and the United States as far as the Rocky Mountains, in which region it is used for sleepers and telegraph posts. When one reaches the Rockies the place of the Jack Pine is taken by *Pinus contorta*, a variety called *Murrayana* being the so-called Lodgepole Pine. Both these Pines are smallish in size, and are characterized by the fact that while their branches are in definite whorls, between each pair of main branches other branches are produced.

The Three-Leaved Pines

Of the Pines with three needles in the sheath, the so-called three-leaved Pines, there is only one which is hardy in England, namely *Pinus insignis* (*P. radiata*). But there are others in North America which are of the first importance, especially *Pinus palustris* (*P. australis*), the long-leaved Southern Pine or Pitch Pine of commerce (Fig. 95). This tree is indigenous in the southern United States—Florida, Alabama and Tennessee.

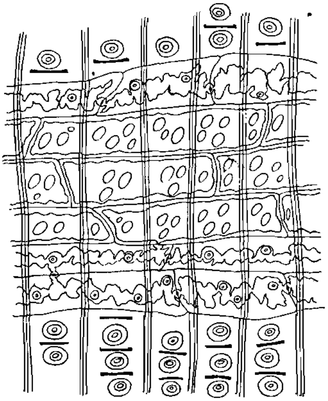

FIG. 95.—L.R.S. *Pinus palustris*. × 400.

It is now about the most important single lumber tree in North America. The wood is very hard, resinous, and is employed extensively in making piles, panels, stairs, bridges, masts, sleepers, etc.

Pinus taeda, the Loblolly Pine, has much the same distribution as the Pitch Pine, but is less valuable. *Pinus rigida* is frequently confused with the Pitch Pine, but is not the true Pitch

Pine of commerce. It is met with in the eastern United States from New Brunswick to Kentucky.

West of the Rockies there is a three-leaved Pine, namely *Pinus ponderosa* (Bull Pine or the Western Yellow Pine), which is met with in California and as far north as British Columbia. It is reasonably hardy in this country. The timber is hard, heavy and strong, and is used for general purposes.

India possesses a three-leaved Pine of great importance, namely *P. longifolia*, whose wood is used for house carpentry, charcoal, etc.

Pinus insignis (*P. radiata*), the Monterey Pine, is the most important of the three-leaved Pines in this country. It is also a very important tree in New Zealand and the Cape. In these two countries, in fact, it is considered the most important exotic tree, and it gives an enormous yield of useful timber, which in New Zealand is largely used for butter boxes.

The wood of the three-leaved Pines is characterized by the possession of resin ducts, while the ray parenchymatous cells have two or more pits to each vertical tracheid.

The Five-Leaved Pines

The five-leaved Pines (Fig. 96) have ray tracheids with smooth walls; while the ray parenchymatous cells have either rhomboidal, elliptical or lenticular pits, often two pits to each vertical tracheid. In Europe there are two species represented in this group, namely *Pinus Cembra* (the Swiss Stone Pine) and *Pinus Peuke.* The former is a native of the Alps, the Carpathians and the Urals, and spreads throughout Siberia to Kamschatka. It is a very resinous timber, and is largely employed in the construction of Swiss chalets.

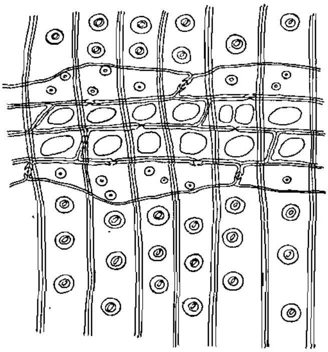

FIG. 96.—L.R.S. *Pinus strobus.* × 400.

Pinus Peuke is met with in Roumelia, Transylvania and Macedonia, where, however, it is of little importance.

North America possesses three important five-leaved Pines. (1) *Pinus Strobus*, the Weymouth or the White Pine, which is a native of Canada and the eastern United States, but not invading the Rockies or extending to the western slopes.

A few years ago it was the most important single lumber tree in North America, but it now ranks about third in the United States. The timber is soft, light, compact and non-resinous, and is very valuable for internal carpentry.

(2) *Pinus monticola* is the representative of the Weymouth Pine, met with in the Rockies and to the west of that range. It is known in America as the Western White Pine, and possesses timber very much the same as *Pinus Strobus*, but it is of much less importance, because it is much scarcer and is far from the coast, and consequently difficult to exploit. Both of these trees suffer enormously from the White Pine Blister Rust, so much so, in fact, that in Europe their further cultivation is rather problematical.

(3) *Pinus Lambertiana* (the Sugar Pine or Cork Pine) is also met with in the Rockies and in the west of that range, and is reasonably hardy in this country. It possesses a very large cone, and the seed is an important article of human consumption amongst the Indians of the Rocky Mountains.

India possesses one five-leaved Pine of first-class importance, namely *Pinus excelsa*, the so-called Himalayan Pine or the Blue Pine. This species is quite hardy in this country, and is largely planted for ornamental purposes. It is practically immune against the attack of the

Blister Rust. In India the timber is used for sleepers, tea boxes, and housework, and it is also tapped for resin.

The Spruces

Coming within the definition of ray tracheids with smooth walls are the Spruces, whose ray parenchymatous cells have oblique slit-like pits and whose tracheids are often spirally thickened. Of the Spruces we have *Picea excelsa*, the Norway Spruce (Fig. 97), the so-called Baltic Whitewood. It extends from the White Sea to the Pyrenees and eastwards to the Urals. It is of much importance in this country, where it is used for the cheaper kinds of internal woodwork, scaffold and telegraph poles, ladders, oars, pit

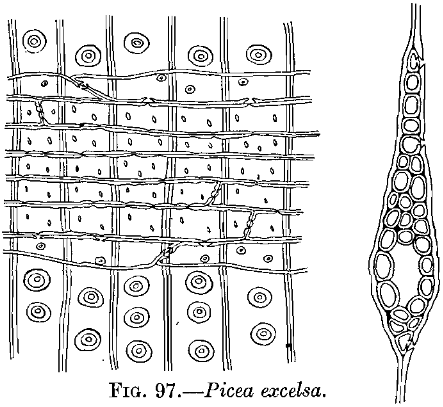
FIG. 97.—*Picea excelsa.*

props, toys and musical instruments. The great bulk of the cellulose which is made into paper is derived from a species of Spruce.

The Serbian Spruce is the only other Spruce native in Europe. It grows very straight and tall, and is used for masts.

In North America there are many species of *Picea*, one being of peculiar interest in Europe, namely *Picea sitchensis*, the Menzies Spruce or Sitka Spruce. In North America it is known as the Tideland Spruce and the Silver Spruce. It is distributed from Alaska to California, being found in the lower river valleys. It is used for all purposes, and especially for aeroplane construction.

To the east of the Rockies three Spruces spread over Canada and the United States, namely *Picea alba* (*canadensis*), White Spruce; *Picea nigra* (*mariana*), the Black Spruce; and *Picea rubra* (or *rubens*), the Red Spruce. These are rather small-sized trees, but in the aggregate give an enormous quantity of lumber, which is used for structural purposes, telegraph poles, railway sleepers, and for wood pulp.

Picea Engelmanni is met with in the Rocky Mountains, from New Mexico, through Arizona to British Columbia and Alberta. This is the Spruce that one sees so much of in travelling through the Rocky Mountains, where it is a beautiful tall tree with a straight stem. Curiously enough, it does not seem to thrive in Europe.

Picea Morinda or *Smithiana* (Fig. 98), the so-called Himalayan Spruce, is a very beautiful species which grows well in this country. It is used for carpentry, packing cases, etc.

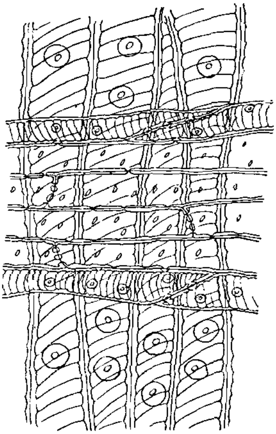

FIG. 98.—*Picea Smithiana.* × 400.

Japan possesses a great number of Spruces, such as *Picea Ajanensis*, *Alcockiana*, *polita* and *obovata.* Central Asia has one called *Picea orientalis*, which grows well in this country.

The Larches

Very closely connected with the Spruces is the Larch (Fig. 99), which is easily distinguished from the Spruce by the possession of dark-coloured duramen and narrow sap wood, whereas the Spruce has got no duramen. The bark is quite different in the case of these two trees, that of the Larch being much thicker and of a rosy red colour. When looked at under the microscope the two timbers are very much alike, the main difference being that the ray tracheids in the case of the Spruce have often got fine projections on the walls, while in the case of the Larch there are generally no such projections.

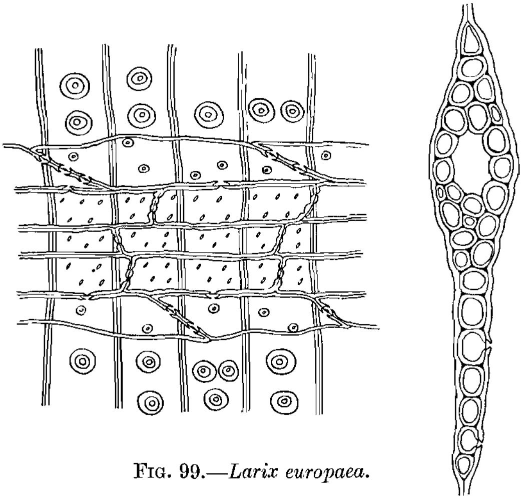

Fig. 99.—*Larix europaea.*

In Europe there is the European Larch (*Larix europaea*). It is a native of the Alps and the Carpathians. In this country it is the great timber for outdoor uses on estates, especially for fencing.

In Siberia there is one called *Larix sibirica*, with a magnificent straight-grown stem. In this country it does not grow well on account of the fact that it is affected by late frost.

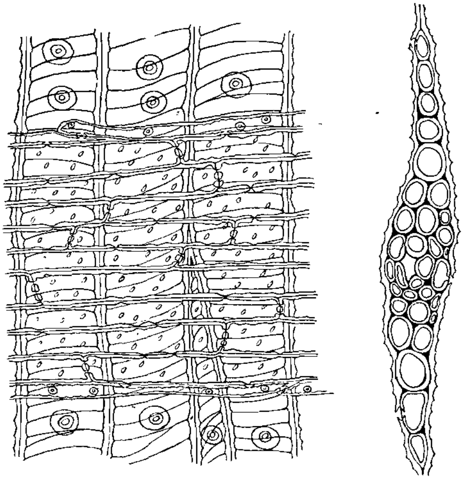

Fig. 100.—L.R.S. *Pseudotsuga Douglasii.*

North America has got several Larches, of which the largest is *Larix occidentalis*, met with in Montana, Idaho and Southern Alberta. There it attains a height of 200 feet, and is the largest species known. It has been tried in this country but is not very successful. *Larix americana* (also known as *pendula* or *microcarpa*) spreads all over the eastern province of Canada and the eastern United States, and is met with in swamps. The tree does not attain to a large size, and is much affected by the large Larch Sawfly Caterpillar, which has about exterminated it in North America.

Japan possesses three or four species of Larch, the best known being *Larix leptolepis*, which is now extensively cultivated in Europe. It is practically immune to canker, and is very fast-growing in youth, and undoubtedly one of the most important introductions into this country. Other Japanese Larches are *Kurilensis* and *Dahurica*, but these are of much less importance than *leptolepis*.

The Douglas Fir

The genus *Pseudotsuga* (Fig. 100) falls into this category, the timber possessing ray tracheids with smooth walls, ray parenchymatous cells with oblique slit-like pits, and tracheids with spiral growth. The Douglas Fir is the most important species of this genus, and, in fact, it is the most important introduction into Europe. It is now the most important lumber tree in the United States of America and Canada, where it is met with on the western slopes of the Rocky Mountains. The timber is very durable, and is used for making masts and all purposes of carpentry. The timber is apt to be confused with Larch, from which it is distinguished by the fact that the tracheids of the former are marked by conspicuous spiral thickening.

The timbers we have been considering all agree in this respect, that they have tracheids with rays and resin ducts in the wood. The next group also contains timbers with tracheids in the rays, but normally no resin ducts. Although the Cedar contains normally no resin ducts, these may be present in trees which are injured or suffering from disease. Such ducts are called traumatic or pathological, and are met with in all conifers under abnormal circumstances.

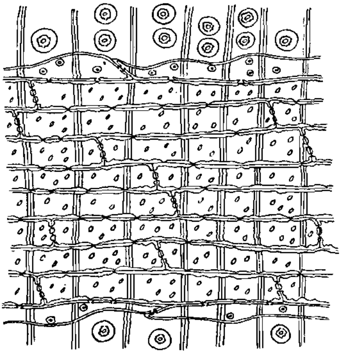

FIG. 101.—L.R.S. of *Cedrus Deodara.* × 400. Note the scalloped margin of the torus.

The Cedars

Cedrus falls into this group. This timber is characterized by the fact that the bordered pits have got tori with an undulating scalloped margin (Fig. 101).

While there are a number of trees called Cedars in America, for instance Red Cedar, White Cedar, Virginia Cedar, and so on, they do not belong to the genus *Cedrus*. There are only four true Cedars in the world, the first being the Cedar of Lebanon (*C. Libani*), another the Cedar of Mount Atlas (*C. atlantica*), a third the Cedar of the Himalayas (*C. Deodara*), and a fourth, which is a variety of the Cedar of Lebanon, found in Cyprus. Of these the most important is the *Cedrus Deodara*, or the

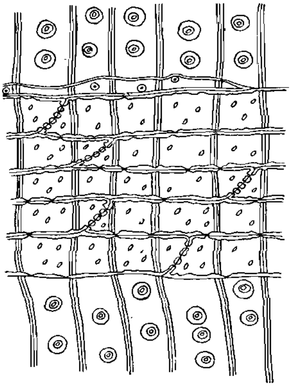

FIG. 102. L.R.S. of *Tsuga albertiana*. × 400.

Himalayan Cedar, which is largely used in northern India for sleepers.

The Hemlocks

The genus *Tsuga*, or Hemlocks, agrees with Cedar in the general structure of its timber, but the tori of the pits have got a smooth margin (Fig. 102). There are two important species of *Tsuga*, namely *canadensis* and *albertiana*, the former being met with from the Rockies eastwards, in Canada, and the United States, the latter being present in the Rockies and to the west of that range. Both are important as lumber trees, but the quality of the timber is not considered very high; it is used in general carpentry. *Tsuga canadensis* does not grow very well in this country, being generally a large

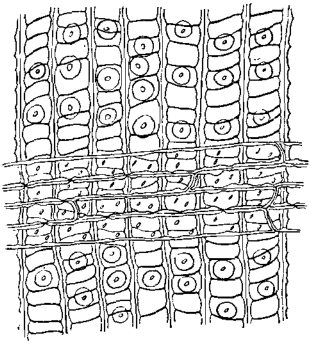

FIG. 103.—L.R.S. of *Taxus baccata*. × 400.

misshapen bush rather than a fine tree. *T. albertiana* grows well here, and generally keeps its leader until late in life.

The Yew

The third group of conifers are those in which the timber contains normally no ray tracheids or resin ducts. In the first subdivision of this group pits in the vertical tracheids are usually in one row. Into this group there falls *Taxus baccata*, the Yew (Fig. 103). This tree is characterized by the possession of well-marked duramen, and the tracheids are marked by very prominent spiral thickening. The Yew is of too small a size to be of much importance, but it furnishes timber which is very durable, and is excellent for estate purposes, such as fencing, and it is also used for furniture-making.

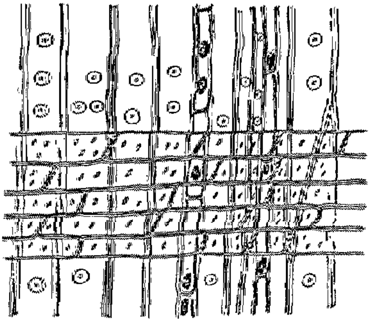

FIG. 104. L.R.S. *Juniperus communis.* × 400.

Junipers and Thuja

The rest of the trees coming under this section have no spiral thickening in the tracheids, and to differentiate them we depend upon the depth of the medullary rays, which in *Juniperus* and *Thuja* are not usually more than seven cells deep; whereas in *Abies* and *Cupressus* many of the rays are more than seven cells deep. To differentiate *Juniperus* and *Thuja* we depend on the tangential walls of the ray parenchyma, which in *Juniperus* are generally straight, whereas in *Thuja* they are often curved. In *Juniperus* there is also abundant vertical parenchyma in the autumn wood, whereas in *Thuja* such parenchymatous cells are much scarcer.

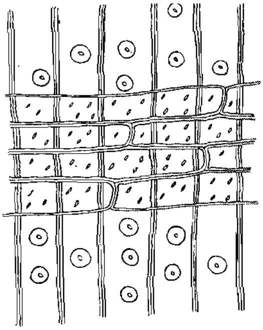

FIG. 105.—L.R.S. *Thuja plicata*. × 400.

Juniperus communis (Fig. 104) is of very little economic importance, although when well grown it is used for fencing purposes. *J. virginiana* is the Pencil Cedar, which furnishes the best wood for lead pencils.

Thuja plicata, or *gigantea* (Fig. 105), furnishes timber of the highest importance in the western seaboard of North America, where it is known as Red Cedar and is chiefly used for shingles.

The Silver Firs and Cupressus

To differentiate *Cupressus* and *Abies* we must depend upon the presence of duramen in the former and not in the latter; and while the wood of *Abies* is white, that of *Cupressus* is reddish. There are a great number of species of *Abies* distributed throughout the world, of which the most important are *Abies pectinata* (Fig. 108),

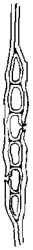

FIG. 106.—Tan. Sect. of *Thuja*. (Note shape of ray cells. Cf. *Cupressus*.)

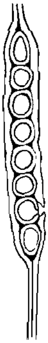

FIG. 107.—Tan. Sect. of *Cupressus*. (Note shape of ray cells. Cf. *Thuja*.)

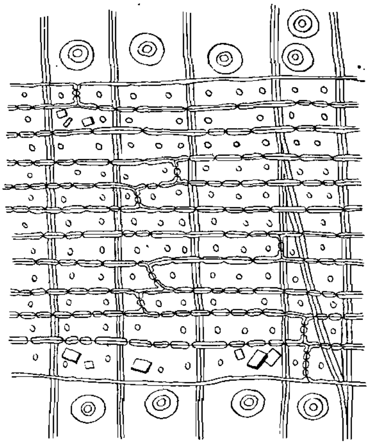

Fig. 108.—*Abies pectinata.* × 400.

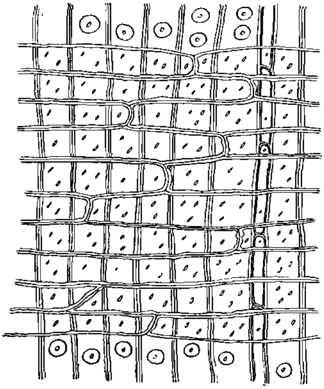

Fig. 109.—L.R.S. of *Cupressus macrocarpa.* × 400.

widely distributed throughout Central Europe. There it is met with in the Vosges, in the Carpathians, and in the Black Forest, where it is used for carpentry, but it is not so valuable as the Spruce.

Of the species, *Cupressus macrocarpa* (Fig. 109) is probably the most important, this tree being now planted in many parts of the world. It was originally a native of California, where it is known as the Monterey Cypress. It is a fast-growing tree, stands exposure to sea breezes well, and also grows on chalk.

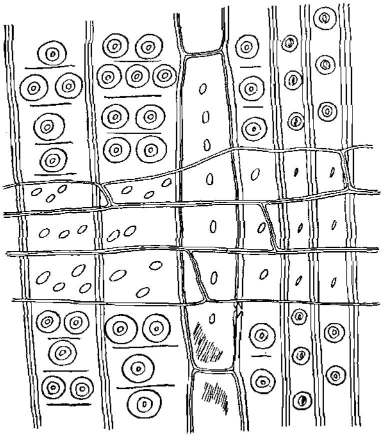

FIG. 110.—L.R.S. *Sequoia sempervirens*. × 400.

In certain conifers the pits of the spring vertical tracheids stand in more than one row. To this

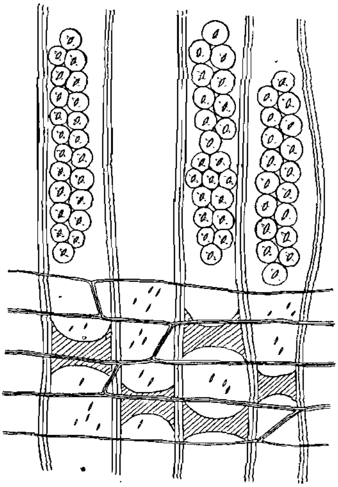

FIG. 111.—L.R.S. of *Agathis* (=*Dammara*) *australis*. × 400.

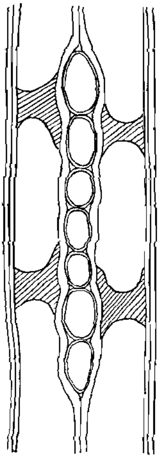

FIG. 112.—Tan. Sect. to show gum-plates in *tracheids* next the ray.

group belongs *Sequoia*, of which the most important, from the timber point of view, is *Sequoia sempervirens* (Californian Redwood, Fig. 110). This tree is limited in distribution, and the supply is rather scarce. It is very valuable for high-class joinery. The timber is characterized by large pits in two or three rows and by the presence of much parenchyma.

The Kauri Pine

Another timber which may be grouped with *Sequoia* is *Dammara Australis* (the Kauri Pine, Fig. 111), met with in the northern island of New Zealand. The supply, however, is now very scarce, but it produces the highest quality of timber for internal woodwork. The pits here are small and often in patches, and there are resin plates conspicuously distributed throughout the wood (Fig. 111).

Synopsis of the Microscopic Characteristics of the Chief Genera of Coniferous Timbers

I. TRACHEIDS IN RAYS. RESIN DUCTS IN WOOD.

A. Ray tracheids with irregularly thickened (reticulate) walls.

Ray parenchyma with rhomboidal or elliptical pits.

(*a*) Ray parenchymatous cells with only one pit to each vertical tracheid, the two-leaved Pines (e.g. *P. silvestris*).

(*b*) Ray parenchymatous cells with two or more pits to each spring vertical tracheid, the three-leaved Pines (e.g. *P. palustris*).

B. Ray tracheids with smooth walls.

(*a*) Ray parenchymatous cells with rhomboidal, elliptical, or lenticular pits, often two to each vertical spring tracheid, the five-leaved Pines (e.g. *P. excelsa*). Ray tracheids may be absent.

(NOTE.—All the Pines possess duramen.)

(*b*) Ray parenchymatous cells with oblique slit-like pits. Tracheids sometimes spirally thickened.

(1) Epithelial cells of ray ducts—usually 7-11 in number.

(*a*) Ray tracheids usually with fine projections on walls; no duramen. *Picea* (e.g. *Picea excelsa*).

(*b*) Ray tracheids usually without projections; with duramen. *Larix* (e.g. *L. europaea*).

(2) Epithelial cells of ray ducts 5-6 in number. Spiral thickening of tracheids very

marked in spring wood. With duramen. *Pseudotsuga* (e.g. *P. Douglasii*).

II. TRACHEIDS IN RAYS; NORMALLY NO RESIN DUCTS.

A. Tori of bordered pits with undulating (scalloped) margin. With duramen. *Cedrus* (e.g. *C. Deodara*).

B. Tori of pits with smooth margin. Duramen indistinct. *Tsuga* (e.g. *T. Albertiana*).

(NOTE.—In *Tsuga* ray tracheids often very short and obscure or altogether absent. Usually conspicuous resin cells on outer margin of autumn wood.

III. NORMALLY NO RAY TRACHEIDS OR RESIN DUCTS.

A. Pits of vertical tracheids usually in one row.

(*a*) With spiral thickening; duramen. *Taxus* (e.g. *T. baccata*).

(*b*) No spiral thickening.

1. Rays not usually more than 7 cells deep.
    - (i) Tangential walls of ray parenchyma straight. Vertical parenchyma fairly abundant in autumn wood. Duramen. *Juniperus* (e.g. *J. communis*).

(ii) Tangential walls of ray parenchyma often curved, ray cells often contracting towards ends. Vertical parenchyma scarcer. Duramen. *Thuja* (e.g. *T. plicata*).

2. Many rays more than 7 cells deep.
   (i) Wood white. No duramen. *Abies* (e.g. *A. pectinata*).
   (ii) Wood reddish. Ray cells contracting towards ends, tangential walls often curved and locally thickened. Duramen. *Cupressus* (e.g. *C. macrocarpa*).

B. Pits of spring vertical tracheids in more than one row.

(*a*) Pits large, in two to three rows. Vertical parenchyma. *Sequoia* (e.g. *S. sempervirens*).

(*b*) Pits small, often in patches. Resin plates common. *Dammara* (e.g. *D. australis*, Kauri Pine).

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